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MINUTES OF THE EXPLOSIVES SAFETY SEMINAR (14TH) HELD AT MARRIOTT HOTEL, NEW ORLEANS, LOUISIANA, ON 8-9-10 NOVEMBER 1972

Department of Defense Explosives Safety Board
Washington, D.C.

12 February 1973

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FOURTEENTH ANNUAL

EXPLOSIVES SAFETY SEMINAR

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MINUTES

DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD
WASHINGTON, D C

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MARRIOTT HOTEL

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8-9-10 November 1973

Conducted by

Department of Defense Explosives Safety Board

Washington, D. C. 20314

PREFACE

This Seminar is held annually as a medium by which there may be a free exchange of information regarding explosives safety. With this idea in mind, these minutes are being provided for your information. The presentations made at this Seminar do not imply indorsement of the idea, accuracy of facts presented, or any product, by either the Department of Defense Explosives Safety Board or the Department of Defense.

William Cameron III

WILLIAM CAMERON III
Colonel, USAF
Chairman
12 February 1973

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WELCOME ADDRESS

Colonel William Cameron III, USAF, Chairman
Department of Defense Explosives Safety Board

Good morning Secretary Shillito, General Miley, Mr. Gerber, Admiral Riera, other distinguished guests, ladies and gentlemen. Welcome to the 14th Annual Explosives Safety Seminar.

This is my third year as your host and I am extremely pleased to see so many of you back again this year. Furthermore, I wish to extend a special welcome to all who are attending for the first time.

Prior to proceeding, I would like to take this opportunity to introduce the Service Board Members. The United States Army Member, Colonel Charles W. Hayden; the United States Navy Member, Captain J. N. Howard; The United States Air Force Member, Colonel J. P. Huffman, Jr.

I believe we have a good program with topics of interest to all. These presentations and discussions will work for the common good of our profession. The bond which brings all of us together is the search for the common good. In our profession, providing for the common good is to provide safe environments for workers in our explosives plants, provide that our munitions and explosives do not endanger families outside our plants and provide safe transportation methods, equipment, and facilities to move our munitions throughout the world. This is the bond which brings us together.

Note our excellent timing of this year's seminar! Yesterday we voted to reelect a President; last night we listened to the returns; joyfully or tearfully; in any case, the President is the choice of the people! Now we can say - let the ranks be closed and pull together for the common good.

With clear thinking and open minds we approach a subject that can be supported 100% by all. The ways and means to improve explosives safety. The theme chosen this year is "Practical safety versus theoretical safety?" We hope that the discussions will have the proper mix of both.

To set the stage for our theme and our keynote speaker, we plan to show a short film entitled "ESKIMO I," produced by the Board. Some of you may recall from last year's seminar that the Explosives Safety Board described an ongoing test program to determine new and hopefully reduced safety distances between igloos. The first major test has been completed and a documentary film outlining the test and its results is what you will see.

I believe you will find the film to be most interesting and be pleased to note that it is one of the few rated for family viewing.

Film

I might add that a special session scheduled for Thursday morning at 1000 hours will give you an opportunity to again see the film and hear detailed discussions of the test and our future test plans.

PRACTICAL SAFETY VS THEORETICAL SAFETY?

Honorable Barry J. Shillito
Assistant Secretary of Defense (Installations & Logistics)
Washington, D.C.

Ladies and gentlemen, members and friends of the Explosives Safety Board. It was with very great pleasure that I accepted the invitation to address this 14th Annual Explosives Safety Seminar.

I am especially pleased because of the involvement and the success this Administration has had in advancing the cause of safety. Certainly when President Nixon signed the Occupational Health and Safety Act in December of 1970, a far reaching process was begun which will improve the working conditions of almost every worker in the United States. Many of you who are employers have already felt the impact of this Act, as have we in Government. President Nixon said in his Executive Order implementing Section 19 of the Act, "As the Nation's largest employer, the Federal Government has a special obligation to set an example for safe and healthful employment. It is appropriate that the Federal Government strengthen its efforts to assure safe and healthful working conditions for its own employees." This is one of the things we are doing here today, and have done at the previous 13 Explosives Safety Seminars. We are strengthening our efforts and setting an example. It is particularly gratifying to me to see so many of you from industry, the academic world, and foreign Governments also here today. This demonstrates again that cooperation between Government and industry in furthering the general welfare is not only achievable, but is an existing fact of life. The Government-industry community dealing with explosives has always demonstrated a concerned, sensitive and active interest in safety and I am heartened to note that by your presence here you affirm that this interest has not slackened.

I spoke of the Occupational Health and Safety Act. I am sure that most of you have heard it praised as a great step forward, and you have heard it condemned as Government meddling in private industry. The first attitude is certainly true. If the latter is, it is only so in a limited degree. However, attitudes on safety which were prevalent a few years ago are unacceptable today. Have you ever heard a statement such as, "Well, two people were killed, but what could you expect on a job like that? Lucky it wasn't more." Yes, lucky it wasn't more. But what should we expect and should luck be involved? Could the job have been made so safe that no one was killed -- or even injured? There are those who believe that nearly all activities can be made that safe or if they cannot, that they should be prohibited.

The theme of this Seminar is directly concerned with opposing views such as these -- the theme is "Practical Safety Versus Theoretical Safety?" The question implied is on the order of "is there a conflict between the two?" Will we forever have opposing views on how safe we can be or can we bring practice into phase with theoretical limits? If not, how shall we determine what is a reasonable and practical level? Who shall make the determination and how shall it be enforced?

Since you will be examining these questions in detail, it may be helpful to consider a few of the obstacles to complete safety that we find in the world today, and how they influence our thinking.

The essence of any consideration of safety is a consideration of people. But people often put safety in second place - or third - or fourth. How many of you used your seat belt the last time you rode in a car? How about your shoulder belt? Did safety take a second place to convenience - you didn't want to take the time - a third place to comfort - the belts are a little tight - and a fourth place to vanity - you're a good driver and don't have accidents? How many have safety glasses and wear them when you are using power saws, drills or grinders? Perhaps you engage in recreational activities where the degree of danger or a semblance of danger is part of the attraction?

These examples illustrate an important human characteristic - unless a danger is perceived to be real and immediate, people tend to dismiss it as unimportant.

So, in determining what is practical and in theorizing what is an absolute limit, we must always keep in mind that we are dealing with people and that perfection may not be attainable.

Of course, the consideration of people is inseparable from the consideration of things - materials, machines, processes. Are these any more controllable and predictable than people? Probably yes. We can design processes that are completely predictable. But here again we must recognize human psychology. If we design a process that has only one chance in one million of causing a fatal accident, most people would be willing to work with it. But, put 50 people on the production line repeating the process three times a minute and, on the average, one person would be killed every two weeks. Suppose our process had only one chance in one billion of going wrong? Under the same conditions, only one person every 40 years would be killed. Would you take the chance? If you knew that you had a five-year production run on two shift operation coming up, would you take the 25 percent chance that one person would be killed.

Perhaps you would and perhaps you would not. But a decision must be made, and management must make it. The production worker, the truck driver, the soldier in the field does not have the information or the freedom usually

to decide for himself that a particular action is or is not too dangerous to perform. Management must decide and management must do so in a way that can be justified, that is reasonably clear, that is humanitarian and still gets the job done.

This is the awesome responsibility you have in any essentially hazardous undertaking such as the production and use of explosives.

Being the responsibility of management - safety policy is subject to the same threats to good management as is any other function, and safety is perhaps most critical. If other management techniques are grossly inefficient, time and money are lost and perhaps an enterprise fails. If our management of safety is bad - people get killed. Knowing this, there is a natural tendency by many safety managers at high levels to overmanage.

What is overmanagement? It is the tendency of people who are "where the action isn't" to call the shots for "where the action is." Overmanagement is the bureaucratic disposition to harness the operational manager with restrictive "do's and don'ts" and drown him in reporting requirements.

Overmanagement is the tendency of the people at the top to write SOP's rather than policy - and this tendency - especially in safety - is a natural tendency often born of fear. Yes, fear that if we at the home office do not think of every possibility and provide for it, an accident may happen. Since we can't think of them all, it is an impossible task. How do we avoid this situation? We have to clear the channel between the man who sets the policy and the man who has to carry it out. This means five things:

First, it means setting clear, unequivocal policies that stop short of crossing every "t" and dotting every "i".

Second, it means ridding organizations of staffs that are remote from the actual operations, but whose reviews and commentaries contribute to the problem rather than to the solution.

Third, it means selecting managers on their records of performance -- not on their records of longevity.

Fourth, it means letting the managers who are selected know clearly what is expected of them; that is, pinpointing their responsibilities.

Finally, it means giving those managers the authority they need to meet their responsibilities.

Have we set clear and unequivocal policies on safety? As an example, we have one policy that a weapon will be so designed that no release of a chemical agent that may cause illness or death will occur through the

normal firing system if a weapon is in an accident. This is a policy. But it is not top management's function to design the weapon. Nor is it our function to make technical reviews of the design to assure that it is safe. But it is someone's responsibility, and these responsibilities are well defined in Military Standard 882. The responsibilities of the developer, the procuring agency, the manufacturer, are spelled out. Everyone knows what policy is and what his part in implementing that policy should be. A clear goal with clear responaibilities is established.

I do not claim that we have achieved an utopian organization. But during the past years, we in Installations and Logistics, have searchingly reviewed all 477 Directives and Instructions that were in effect when I assmed this position. As a result, one-third have been modified or cancelled and another one-third will be. Gentlemen, we have the objective in sight and we are making prugress.

Top management is not the only perpetrator of poor administrative practices. I have spoken before on the four threats to good management. Whereas over-management is the first and is the primary sin of the upper levels, the middle and lower levels have their failings also. Again, because of the seriousness of the safety manager's responsibilities, the results of these failings, when they occur, can be catastrophic.

The second of these threats is "under-implementation." Good policies are not worth a nickle unless they are carried out. The manager himself is the key here.

- He has a responsibility to find out what the charted course is. Many managers do not make that effort.

- He has a responsibility to communicate the charted course to those he depends on to help him. Many managers do not make that effort.

- He has a responsibility to make decisions that will cause the policy to work. Many managers would rather look upstream for a decision by committee.

The third threat to managerial effectiveness is "under-involvement." Management today is no "hut, two, three, four" response to command. People are not automatons. As one expert on management styles points out, "The pyramidal, centralized, functionally specialized, impersonal mechanism known as bureaucracy is out of joint with contemporary realities." True, the form remains, but its functional substance has changed. A major portion of today's problems are solved by "adhocracies" of experts -- teams of talents brought together to resolve "this or that" element of a problem. Staying within the neat lines of an organization chart today would bring the entire decision-making process to a crashing standstill. The engineering manager has to work with the manpower specialist and economist. The safety

man has to work with everyone. No manager can be an island unto himself. He has to become involved in order to make the organization tick. The safety manager must involve himself well beyond the confines of his structured niche on the organization chart. Within his own functional orbit he has to involve himself with the people who do the work. A safety manager who spends his time in his own little office instead of roving through the places where the work is being done is headed for catastrophe.

The fourth threat to effective management is "under-motivation." Few of us have the same physical drive today that we had in our "twenties." But there is another kind of drive that should sharpen and strengthen as the years pass. That is the "emotional" drive to do the best job we can in a profession we like for a cause we believe in. It takes a truly dedicated person to sustain his job momentum while in a climate of pained tolerance or nonrecognition which occasionally happens in a safety. The given lip service and little else. A working climate such as this can blunt a manager's emotional drive. Don't let it get to you. You have the responsibility because you have the awareness. Part of your responsibility is to awaken the same awareness in both directions - no matter where you sit - up and down the management chain.

I know that one of the difficulties facing you in your attempts to develop such an awareness - in effect to educate those above you in the management chain - is the very difficult problem that top management has in evaluating your effectiveness.

How can we measure the value and effectiveness of what you are doing? You, when you are most effective, are responsible for things not happening - accidents. But, management cannot conclude from a history of "no accidents" that the safety man has been doing a good job. He may be overzealous and costing the enterprise good hard cash. He may be lax and lucky. But how does management know? If you are going to consider establishing a "practical" level of safety, there must be a means of measuring the cost of that level and the effectiveness of it in management terms - time, manpower, money and materials.

While I will not have the opportunity to attend your working sessions, nor to read all the papers to be presented here, I do note that most of the topics to be covered are technical and deal with methods of improving safety. Fine. This is a worthy objective. But I charge you that you have another problem - more difficult than just improving - this problem is to evaluate yourselves - how well are you doing now and how much you should improve. The problem is to quantify your efforts - and to quantify options that may become available to management. When you can quantify you can convince. When you can measure, you can make decisions. When you can make decisions and convince - you can manage.

In many ways, the frustrations of your jobs as safety experts and mine as manager of our Installations and Logistics programs are similar. No newspaper is going to sing our praises if we do a good job. But one bad contract, one large cost overrun, and you will hear about it from radio, TV, newspapers, and Congress. The same is true for you. One accident and you make the headlines.

So you see, I know some of your problems, and I know it is a difficult task when I say don't come to me and tell me we need to improve safety - I already know this - but tell me how much we need to improve, how to accomplish it, and what it will cost - then I can see to it that the resources are made available - and we can get the job done.

Thank you.

A NEW LOOK AT EXPLOSIVES CLASSIFICATION

W. J. Burns
Department of Transportation
Washington, D. C.

Colonel Coder, ladies and gentlemen, I am delighted to have this opportunity to meet with you and to discuss the Department of Transportation's efforts in explosives classification. The Department of Transportation is in the midst of a complete overhaul of the Hazardous Materials (HM) Transportation Regulations. Part of this effort is directed toward classification. As far as explosives are concerned, the attack is multi-pronged.

We are now in the second phase of a contract with Edgewood Arsenal and General Electric Company. This is preliminary in nature and is aimed at obtaining an outside view of our explosives classification system and suggestions as to how it can be improved.

The Office of Hazardous Materials (OHM) and the Coast Guard have liaison representatives participating in the DODESB Explosive Classification/Compatibility Work Group which is revising the Tri-Service explosives classification procedures document (TB 700-2.....), as well as updating the criteria for explosives compatibility.

With respect to international regulations, the principal United States representatives on the United Nations Organization (UN) committee concerned with explosives regulations are furnished by OHM & DODESB.

We are cooperating with industry groups such as the Institute of Makers of Explosives, as well as with individual manufacturers and shippers, including the military, who have problems.

The DOT Regulations must be revised to reflect advanced technology and operating techniques.

Some of the areas wherein DOT has either implemented changes, or is contemplating them, and for which the United States have presented criteria for adoption by the UN are: take nitrocellulose out of the explosives class regardless of nitrogen content provided it is wetted with water or alcohol; classification of wetted explosives; types of warning placards to be affixed to vehicles: compatibility of explosives with other hazardous materials; modification of classification lists to reflect grouping by generic titles; and compatibility group tests designed to determine hazards of explosives and their assignment to appropriate UN divisions.

It is amazing how much Special Permit exercises reveal about the adequacy or gaps in the Regulations. This is true also with respect to the classification reports which are submitted on the classification of new explosives in accordance with Section 173.86, Title 49, Code of Federal Regulations (CFR).

We have a close working relationship with the modal administrations in DOT, both through the activities of the Hazardous Materials Regulations Board (HMRB), which I chair, and through the modal liaison representatives assigned to my office. Finally, we have the OHM professional staff which couples the feedback from all these activities with its inherent knowledge to develop the new criteria as proposed rule making for consideration by the HMRB.

We must provide explosives classification criteria which clearly distinguish the hazards of these materials from those of other types of HM's, as well as between explosives, themselves. Uniformity of criteria throughout the United States (military and commercial) and compatability at the international level are primary goals. We must come up with a systematic classification system that leaves no doubt what the hazards of a particular material or item are, both from the inherent standpoint and as it is presented for transport. Otherwise we cannot assess the risk(s) involved. Nor can we take the necessary precautions such as improved packaging, handling procedures, quantity limitations or the like.

Why do we need to change the classification system in the first place? We welcome, of course, any constructive suggestions. We hove already a rather lengthy list in mind. Certainly the clearer the picture and the more completely the problem is defined, the better the revised criteria should be. Perhaps a good way to illustrate the sort of questions with which we have been wrestling and which must be dealt with in revising the explosives classification criteria would be to mention some of them:

<u>Question 1</u>: How can we classify on the basis of hazard(s) presented in transport, rather than by end-item use?

<u>Question 2</u>: Are the present required explosive classification tests relevant to transportation?

<u>Question 3</u>: How can you test laboratory quantities of bulk explosives and apply the results to classification of end items or large quantities of bulk material which are offered for shipment?

<u>Question 4</u>: How do you resolve the classic blasting cap dilemma--Class C, if 1,000 or less; Class A, if over 1,000?

Question 5: When is a blasting agent not a blasting agent, or how should you classify nitro carbo nitrates?

Question 6: How can we uniformly classify military and commercial explosives?

Question 7: How can we realistically test packaged explosives?

Question 8: What are the interrelationships between propellants, explosives, organic peroxides, flammable substances and oxidizing materials? When are they explosives? When are they not? What criteria can we establish to properly classify them to assure risk control?

Question 9: What are suitable definitions for liquid, solid, gel, slurry, solution, mixture and paste, to mention a few? And, let us not forget "small quantity".

Question 10: How do we accommodate shipment of samples for testing?

Question 11: How does one consider the fragment hazard aspect?

Question 12: What do we prescribe in the way of non-propulsivity criteria?

Question 13: Should the possibility of sabotage now be cranked into our classification criteria?

Question 14: How do we reconcile the DOT alphabetical A, B, C system with the numerical systems of the UN and DOD?

So much for philosophical background. Let us now look at the classification systems. I have Erskine Harton, who is a Chemical Engineer in my office, with me to help answer any technical questions you might have.

In Table I we notice that both DOD and the UN recognize the distinction between mass detonating explosives and those which progressively detonate and/or produce a predominant fragment hazard. DOT combines these two types into A. If DOT were to adopt the UN system or utilize a combination of the UN numbers and DOT letters, there would be agreement on basic categories. The remaining problem would be that of the seven categories used by the military, four of which express degrees of hazard within the UN 1.2. Since the seven military designations are primarily for storage purposes, there should be some way to resolve the problem in the interests of uniformity in the transportation classification system. I need to emphasize at this point that DOT looks favorably at a classification system that is compatible with the UN. I also must stress the fact that only the Hazardous Materials Regulations Board can modify the DOT HM Regulations.

Now, if you will look at Figure 1, you will see a schematic for testing and classifying bulk explosives in accordance with TB 700-2. End items are tested by normal ignition of an item in a single shipping container and in two shipping containers and subjecting a shipping container to a fire. Propagation in any test means Class A.

Figure 2 is a schematic for DOT tests to indicate forbidden bulk explosives and typing Class A bulk explosives. I wonder how many people here realized that there were this many types of Class A explosives. What are their significance? That is a question we have asked ourselves and the matter is undergoing thorough scrutiny to determine just how meaningful they are. Class B DOT testing involves essentially these same tests and all must be negative -- no detonation or propagation.

Since Class C explosives contain either Class A or Class B explosives there are no bulk tests for Class C. Assignment is by quantity limitation or by testing of the end item.

Figure 3 schematically presents the DOT tests and classification relationships for end items. TB 700-2 does not include a bullet-impact test. It does include a bonfire test, however, as well as detonation and functioning tests of items in various configurations, including confinement.

As I mentioned earlier, the first phase of our explosives research studies by the General Electric Company under our contract with Edgewood Arsenal is complete. We expect to make a final report available in the very near future through the National Technical Information Service. I want now to present a few highlights from that effort.

The investigators present a new concept which classifies and ranks explosives (and could be applicable to certain other HM's) by their ability to initiate, communicate and progress to detonation when subjected to the various stimuli available in the transportation environment. It is referred to as the ICT concept. The approach considers the energy necessary to produce Initiation as an input function-- in other words the external stimulus. Communication and Transition are internally generated energy forces, or output, and are considered indicative of damage potential. Table 2 summarizes the ICT classification criteria.

Table 3 is included to show how the tests in TB 700-2, Title 49 CFR and those proposed by the investigators compare as to applicability for ascertaining Initiation, Communication and Transition characteristics.

Table 4 summarizes the proposed classification tests in tabular form. The initiating test is primarily concerned with determining on a go-no-go basis if a material or item is acceptable for shipment or not.

Figure 4 shows the proposed test methods and classification for bulk explosives in schematic form. The four classes shown, aside from Forbidden, correspond to the four principle UN categories.

Figure 5 is a similar schematic presentation for testing and classifying end items.

Figures 6, 7 and 8 show results of testing various explosive materials and items by the proposed methods. These figures deal with input testing and end item output testing, respectively.

Let me say very clearly that these criteria are recommendations and their inclusion in this presentation in no way implies their endorsement. They represent one of several technical inputs which will be duly considered, as we prepare the official OHM recommendations for the HMRB to consider. I also want to point out that the reported test results should not be interpreted that any particular materials are necessarily wrongly classified at present, because these criteria are proposals only from a source outside DOT and do not represent those in the current DOT Regulations.

A principle part of the follow-on work underway by General Electric is a preliminary study of the interrelationships of explosives, oxidizing materials, organic peroxides and flammable solids. This work is due to be completed early next year.

I hope that my presentation has given you a little insight into our activities and at least a general view of the trend in regulations development. Thank you for your attention.

Table 1. Explosives Definitions Summary

DOT (TITLE 49 CFR)	DOD	UNITED NATIONS
Class A - Detonating or Otherwise of Maximum Hazard	7	1.1 Mass Reacting
	3,4,5,6	1.2 Progressive Explosive and Projection (Fragmentation) Hazard
Class B - Flammable Hazard with Rapid Combustion	2	1.3 Severe Fire
Class C - Minimum Hazard Containing Class A or B in Restricted Quantities	1	1.4 No Significant Hazard

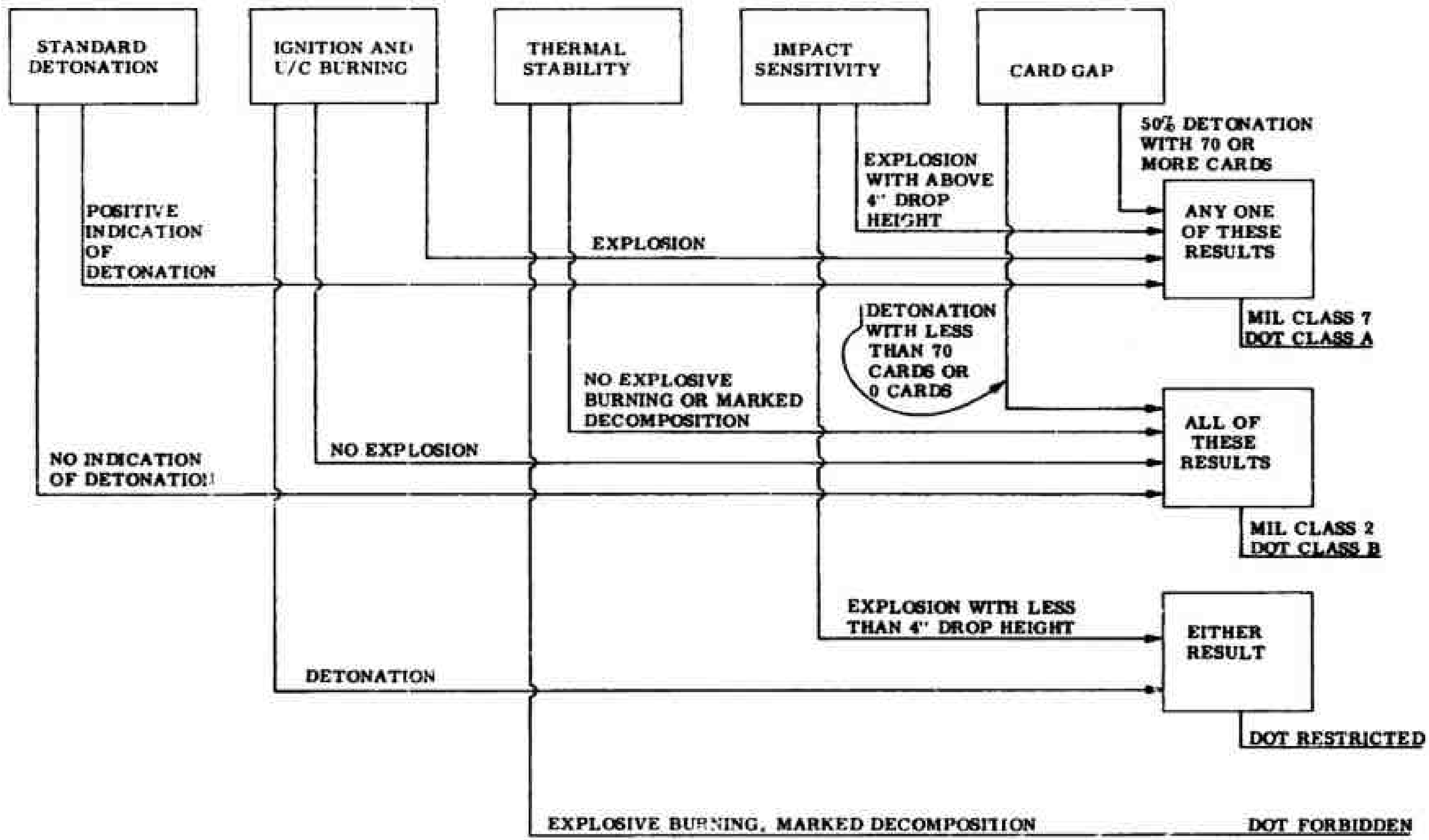

Figure 1. Relationship of TB 700-2 to Classification Requirements

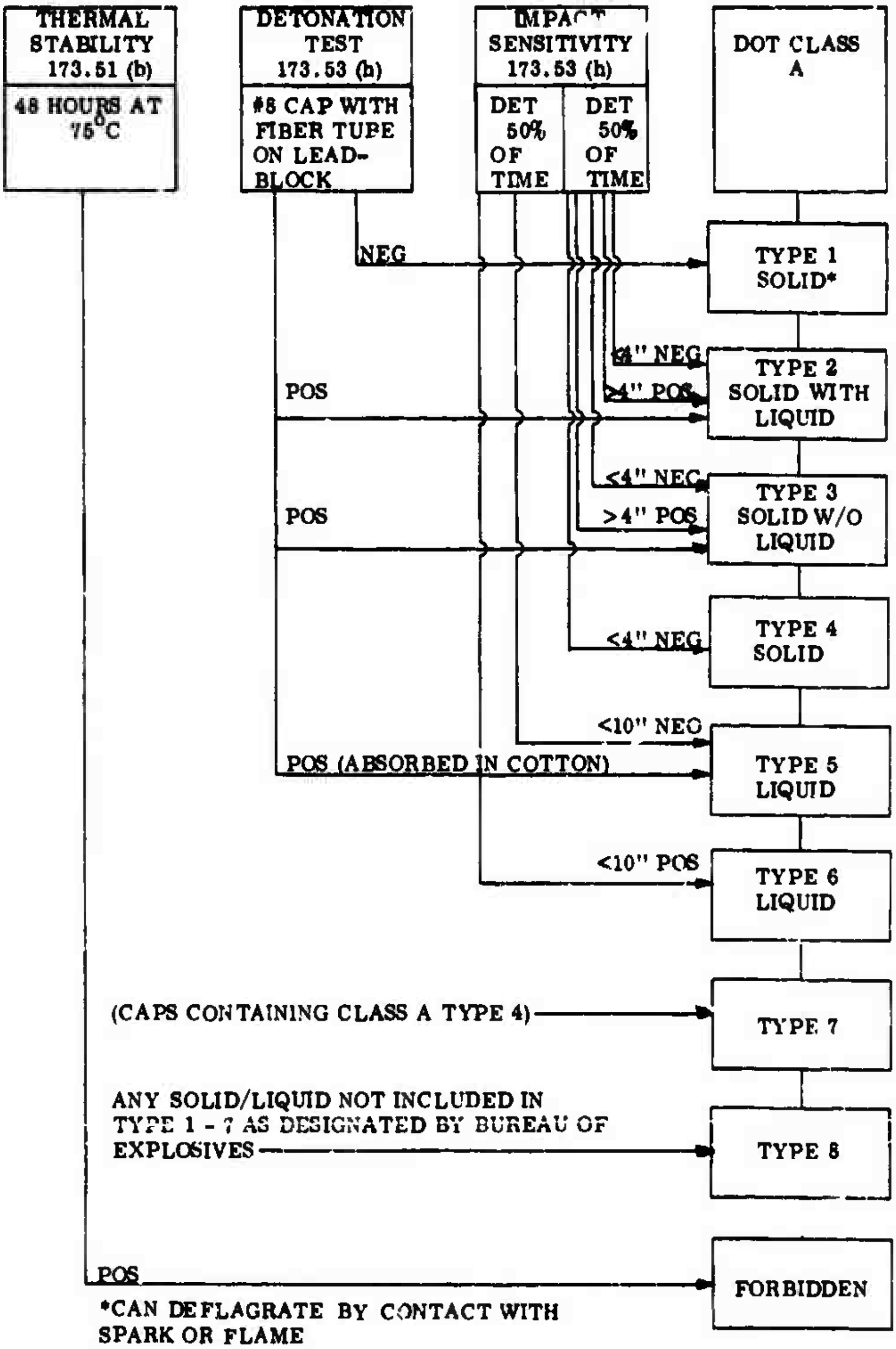

Figure 2 Relationship of DOT (Title FR 49) to Classification Requirements

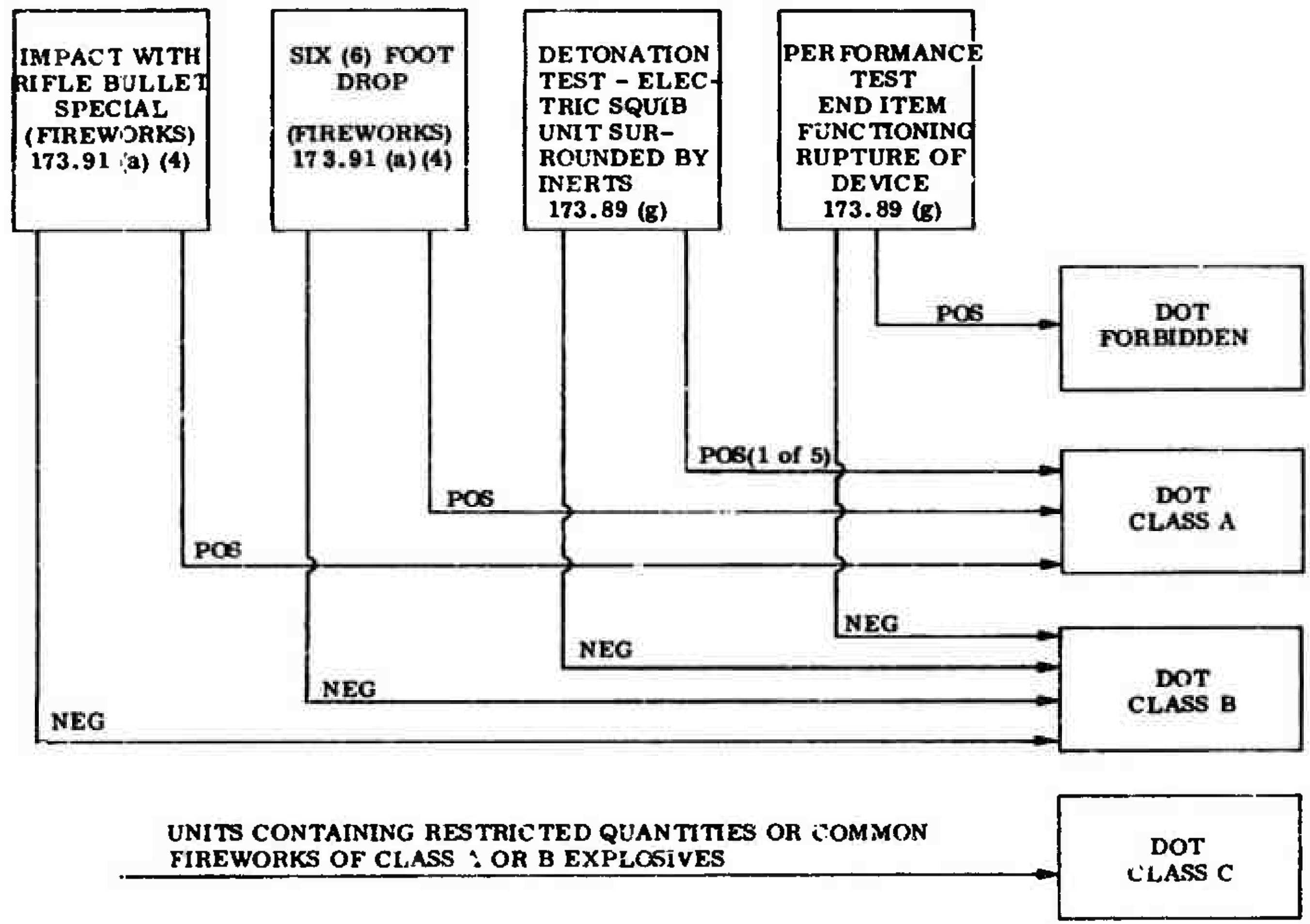

Figure 3. End Item Tests - Title 49 CFR

Table 2. Proposed ICT Criteria for Explosive Classification

ENERGY APPRAISAL	PURPOSE	MECHANISM	PARAMETER	DESCRIPTION
Input	Sensitivity Determination, to determine on a "go - no go" basis if a material is transportable: Acceptable or Unacceptable	Initiation	Pressure	200 lb/ft^2
			Thermal	$160^{o}F$
			Electrostatic Discharge	100 mj
Output	Damage Potential, to classify a given material according to the hazard it presents	Communication and Transition	Mass Reacting	Intrinsically Explosive
			Progressive Reacting	Explosive under confinement
			Fire Hazard Only	Reaction/incident can be contained within an area

Table 3. Correlation Between Candidate Tests and ICT

		Par.	Candidate Test	Initiation	Communication	Transition
Existing TB 700-2 Tests	Bulk Materials	3-8	Detonation			x
		3-9	Ignition & Unconfined Burning	x	x	
		3-10	Thermal Stability	x		
		3-11	Impact Sensitivity	x		
		3-12	Card Gap	x	x	x
	End Items	TYPE				
		A	Single Shipping Container, normal ignition		x	x
		B	Two shipping containers, normal ignition		x	x
		C	Shipping containers subjected to external heat	x	x	x
Title 49 - CFR*	Bulk Materials	173.53 (h) (1) Note 1	Detonation			x
		173.53 (h) (1) Note 2	Impact Sensitivity	x		
		173.51 (b)	Thermal Stability	x		
	End Items	173.91 (b) (4)	Bullet Impact	x		
		173.91 (a) (4)	Six Foot Drop	x		
		173.89 (g) Note 2				x
		173.89 (g)	Performance Test - Single Container			x
Proposed Tests			Spark Ignition Sensitivity	x		
			Burn Rate of Inorganic Oxidizer	x	x	
			Pressure Vessel			x
			Detonation Test			x

*Revised January 1, 1971

Table 4. Summary of Proposed Explosive Classification Tests

TYPE	PACKAGING	CLASS	MECHANISM	PARAMETER	PROPOSED TEST
Input (Sensitivity)	Bulk	Forbidden	Initiation	Pressure	Impact Test - Bureau of Explosives Apparatus, positive reaction in one of 10 trials at $< 4"$ drop height.
	Bulk	Forbidden	Initiation	Heat Transfer	Thermal Stability for Steel Pressure Vessel at $75^{\circ}C$ for 48 hours
	End Item	Forbidden	Initiation	Heat Transfer	Smallest end item configuration for 3 days at $75^{\circ}C$, instrumented with thermocouple to determine any evidence of exothermic reaction.
	Bulk and End Item	Forbidden	Initiation	Electrostatic	Electrostatic Discharge Test - 50 mg sample. Maximum electrical energy for zero probability of initiation. Data related to minimum electrical energy ≤ 105 mj, human capacitor.
				Friction	No requirement. In transportation environment unlike manufacturing environment or other environment no tooling comes in contact with bulk material, therefore, greatest hazard is triboelectric due to sliding of packaged end item, which is considered under electrostatic.
Output (Damage Potential)	Bulk End Item	Mass Reacting Hazard	Communication and Transition	Burn Rate Unconfined	Detonation Test - Steel tube, semiconfined, blast cap. (Bulk) Detonation Test as per TB 700-2 End Item Type "B" (End Item)
	End Item Bulk	Progressive Reacting Hazard	Communication and Transition	Burn Rate and Brisance Confined	Pressure Vessel, squib initiator, rupture disc rated at 30 psi. (Bulk) Large Pressure Vessel for single end item - Rupture disc rated at 30 psi. (End Item)
	End Item Bulk	Fire Hazard	Communication and Transition	Heat Transfer	TB 700-2 End Item, Chapter 3 - Ignition and Unconfined Burning Bureau of Mines Burn Rate Test, RI 7594.
	Bulk and End Item	Minor Hazard	Initiation Communication and Transition	All of Above Parameters	Negative reaction to all of the above tests.

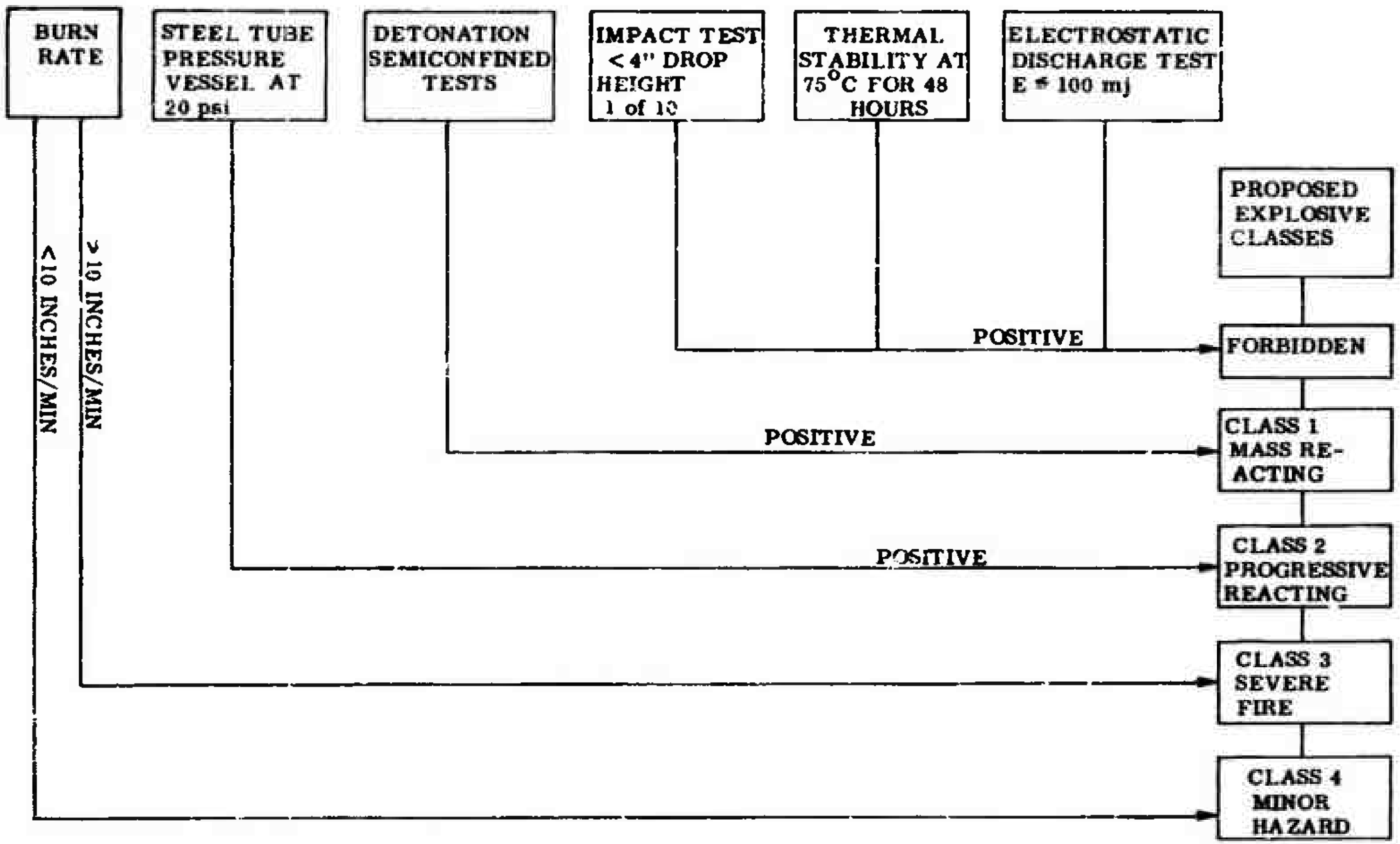

Figure 4 . Proposed Bulk Explosive Classification Scheme

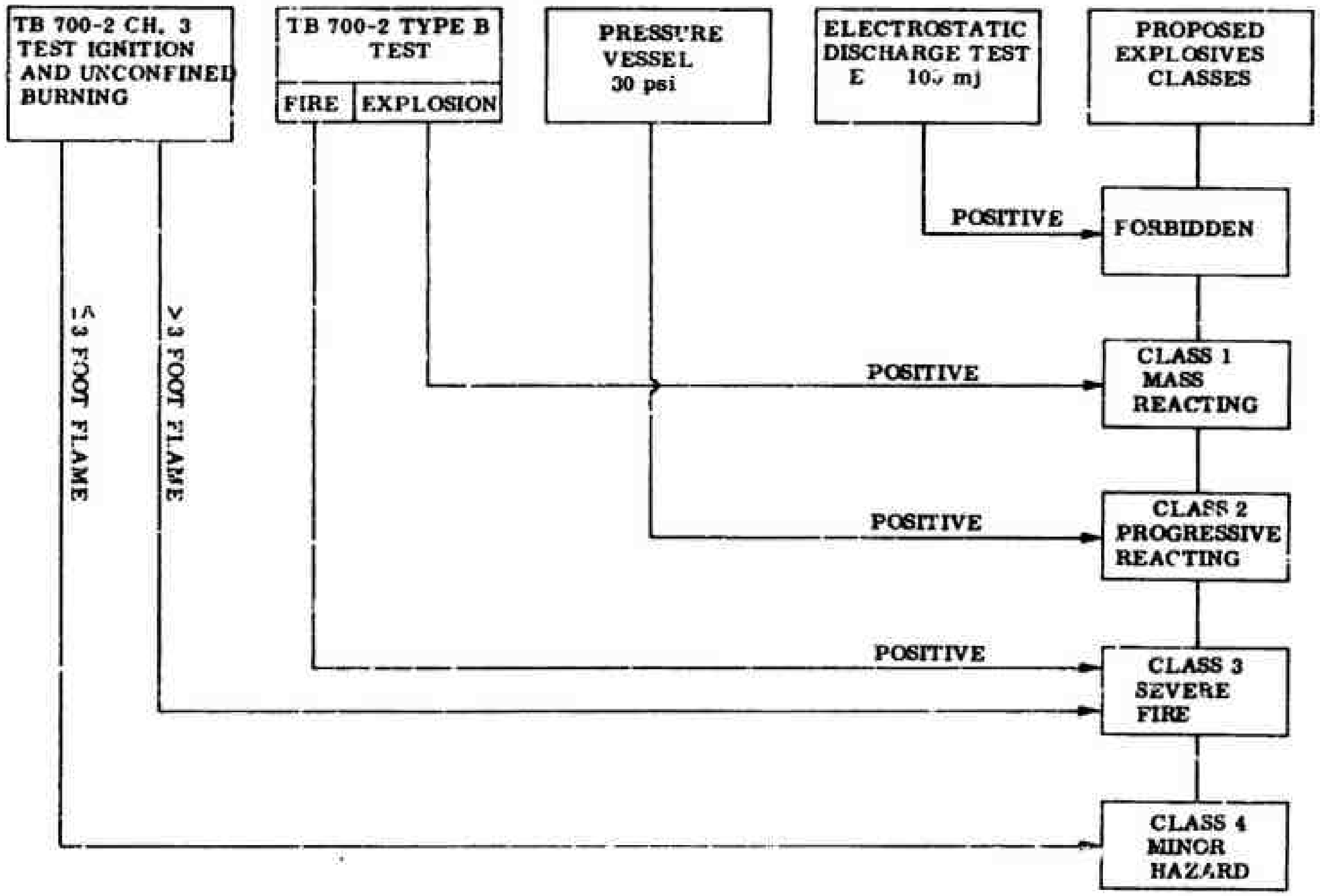

Figure 5. Proposed End Item Explosive Classification Scheme

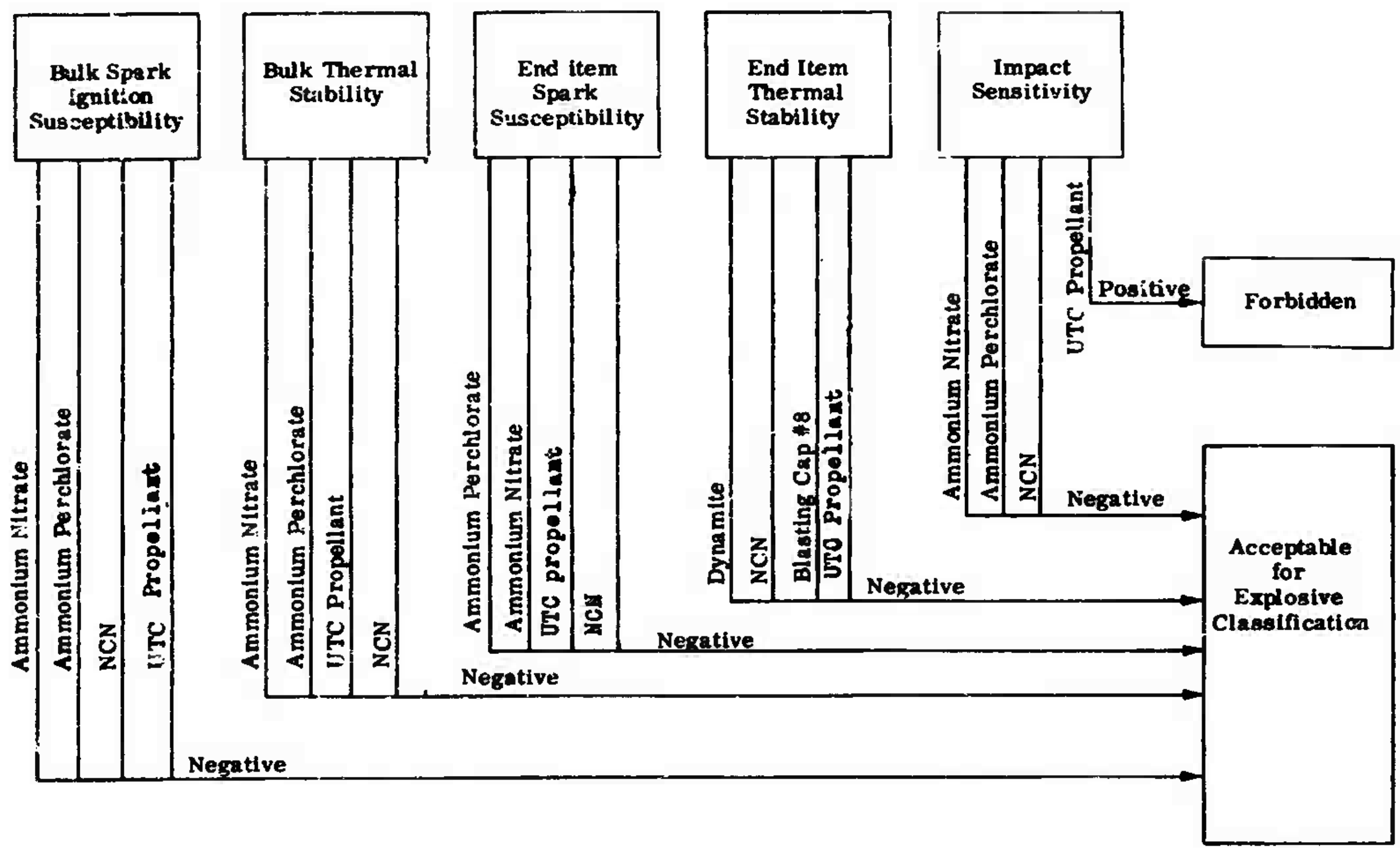

Figure 6. Results of Input Sensitivity Tests

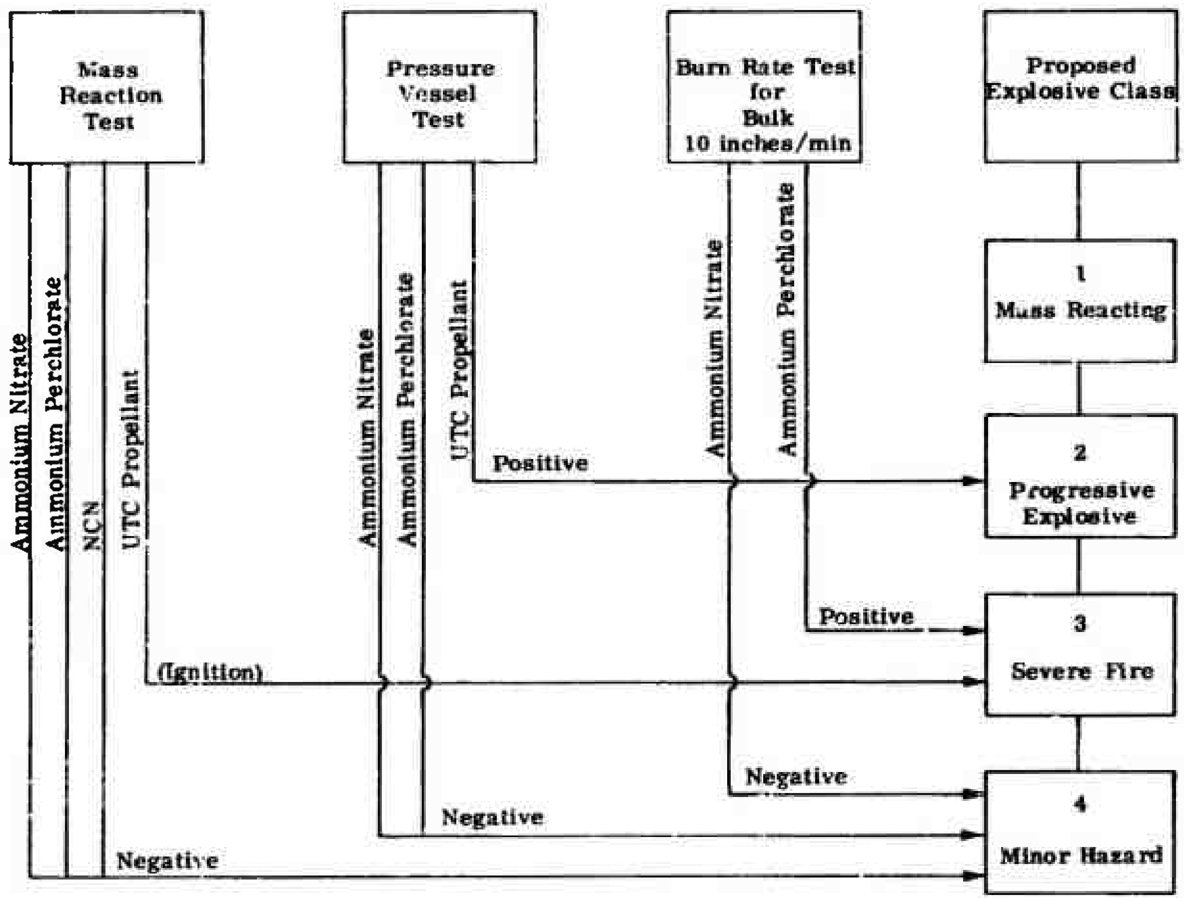

Figure 7. Results of Bulk Output Testing.
Note: Material would be placed in the lowest numbered class for which a positive reaction was obtained.

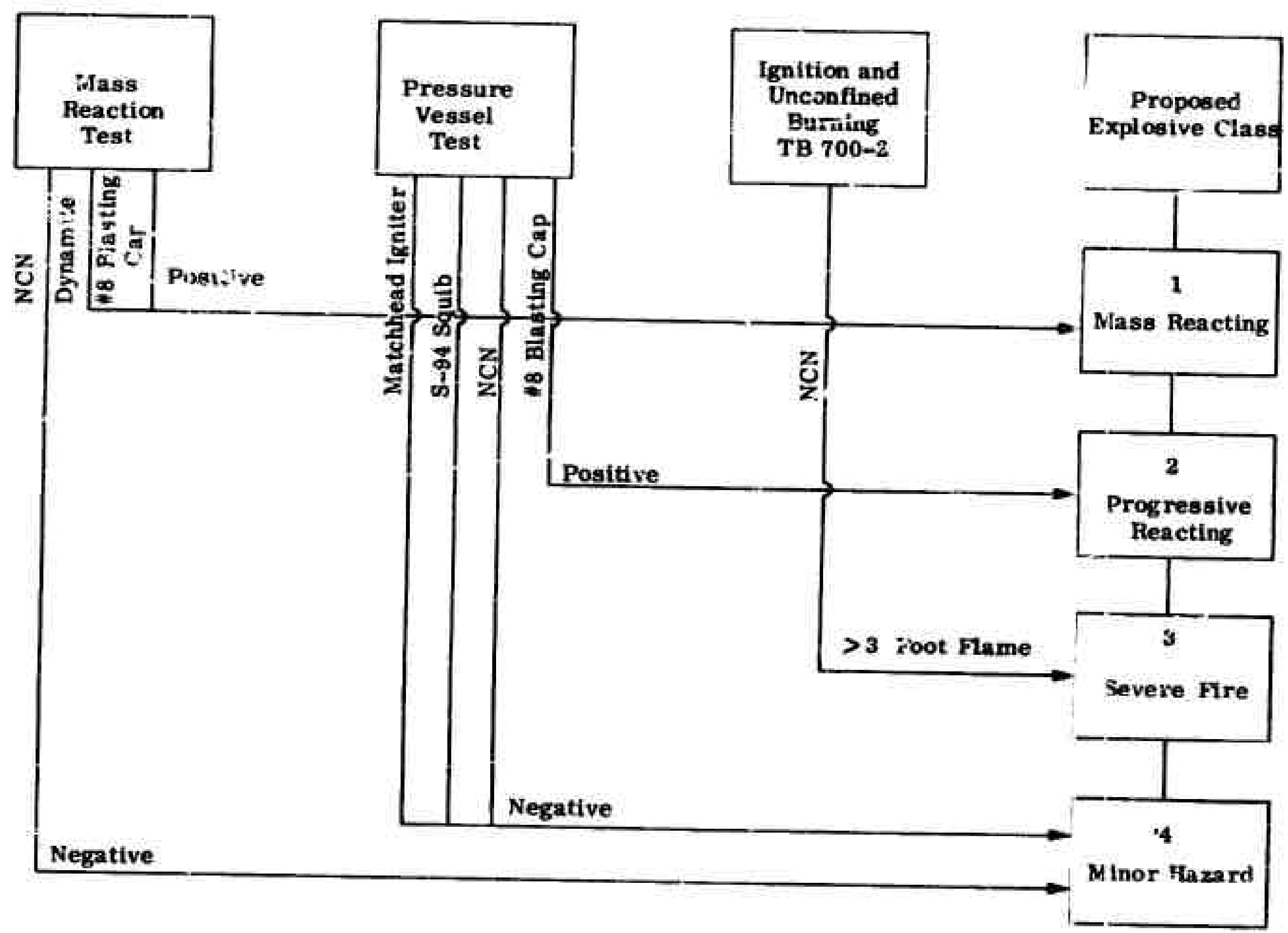

Figure 8. Results of End Item Output Testing

Note: Material would be placed in the lowest numbered class for which a positive reaction was obtained.

HAZARD CONSIDERATIONS RELATING TO FUEL-AIR EXPLOSIVE WEAPONS

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BACKGROUND:

The CBU-55 now in operational use is a 512-lb "all up", cluster weapon containing three contact fuzed BLU-73 Fuel-Air explosive bombs. When the weapon is intentionally released from the delivery aircraft an arming wire is extracted from the FMU-83 dispenser fuze. If the fuze senses an airspeed greater than 70 knots it is enabled, and will function at the time pre-set into the fuze (from 1 to 10 seconds). At fuze function, the aft bulkhead is exposively projected from the dispenser, and three piezoelectric crystals are crushed signaling the FMU-74 bomb fuzes that a proper release has been achieved which causes an interlock to be removed from each fuze. Projection of the aft bulkhead rearward deploys the aft bomb stabilizer which causes extraction of the bomb. Continued extraction of the aft bomb stretches the center bomb stabilizer and removes the bomb fuze probe cover, allowing a collapsed probe to extend to a length of four feet. Probe cover removal also initiates a pyrotechnic delay which will cause the bomb to self destruct in 120 seconds if it has not functioned at impact. Probe extension removes the last interlock allowing the fuze to complete the arming sequence. The process is identical for the center and forward bombs. The result is a linear impact pattern controllable by means of release velocity, dive angle, and dispenser fuze setting. On impact, the fuze functions causing dispersion of the ethylene oxide fuel. Redundant cloud detonators, armed by acceleration are projected into the cloud and function approximately 125 milliseconds after fuze function. The fuel-air cloud is initiated by functioning of one of the cloud detonators.

HAZARD CONSIDERATIONS:

The fuel, ethylene oxide (EO), was selected not on the basis of maximum energy output, but because of the ease of handling and hazard minimization relative to other fuels available at the time the design baseline was established.

EO can not be detonated in the liquid state as can many other materials. This is vividly exemplified by the technique used to disperse the fuel. We detonate .66 lbs. of high explosive in intimate contact with the fuel. In many thousands of tests we have never been able to detonate the fuel until after it has been properly combined with air. The safety benefit resulting is that a detonable explosive is not created until after the fuel has been mixed with air within specific proportions.

The vapor pressure of EO is low as compared to many fuels, (approximately 21 psia at 70 degrees F and 105 psia at +165 degrees F). A low vapor pressure is desirable to reduce the leak rate in the event of an inadvertent leak and to delay the case rupture time in the event of a fire adjacent to the weapon in storage.

The detonation limits exist only within a window from approximately 6 to 24% by volume. An example of this on a temporal scale is the fact that the BLU-73 bomb must be initiated after approximately 70 milliseconds and before 200 milliseconds to achieve a detonation. If it is attempted outside this time window a burn results instead of a detonation.

The fuel is completely soluble in water, thus allowing vapors to be scrubbed from the air by a water deluge system and allowing inadvertent spills to be rendered incombustible.

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I think that it is obvious thst if we were only concerned with the potential hazard of an inadvertent detonstion we would sll be convinced that Fuel-Air Explosives do not increase the normal ordnance hazards.

Of most concern though has been the potential fire and toxicity hazard in the event of inadvertent leakage. A major emphasis has been placed on designing for no leaks and to prove that the design is adaquate during the entire stockpile-to-target sequence.

Before getting into the details of the Safety and Environmental Test Program, I must first spend a few minutes on the subject of fuel leak detectors, a subject which has caused much frustration during the entire development program.

It was recognized at the beginning of the CBU-55 development that precision leak detectors were readily available for monitoring a magazine or other storage area for a fuel leak. Such a detector though would not identify which weapon among many was the leaking one. It seemed reasonable to provide such a detector on each dispenser and also for added ease of isolation, on each shipping container. We have developed a reasonably precise, low cost detector, but unfortunately it is an integrating, non specific detector which will indicate the presence of extremely low, non hazardous, concentrations of fuel given a sufficiently long exposure. Unfortunately, the original intent for the detector (to provide an isolation capability given a sensed leak in the storage atmosphere) escalated instead into it being a signal for immediate concern and disposal if qualified technical personnel were not readily available, even if the concentration within the dispenser were below the flammable limits and there were no vspors leaking into the atmosphere. Throughout the development program we have been plagued with activated indicators which were caused by:

a. Fuel dropped on the painted cannisters during the filling operation and eventually evaporating after being sealed inside the dispenser.

b. Substitution of marking paints which activated the detector, and

c. Most recently a reported large number of activated detectors which were caused by reflections from a red warning flag on a grounding strap inside the shipping container.

These problems have been corrected as the production process has matured and are discussed here because they are indicative of the concern about preventing a potential hazard condition.

SAFETY AND ENVIRONMENTAL (S/E) TEST PROGRAM:

Three iterations of S/E testing was performed.

The first, designated the Diagnostic Test Series, was performed early in the project before firm designs were established. Table 1 describes the tests performed and the results obtained.

The next series of S/E testing was performed on prototype weapons designated P1 models. The results are shown in Tables 2 and 3.

The final S/E test series, performed prior to full production, was conducted with Pilot Production model weapons. The results are shown in Table 4.

In addition to the formsl test programs described a number of specisl tests have been conducted at the request of various organizations interested in a specific potential problem. Examples of these are:

a. Tests to determine the effect on adjacent weapons from a burning weapon

b. Tests to determine if the central burster charge can be detonated given a detonation of the cloud detonator assembly

c. Tests to determine the potential hazard due to contact of various explosives with liquid fuel or vapor

d. Tests to determine if a hazard exists if a leaking weapon were delivered in a routine manner.

The results of these tests have not been included in thi paper because of the time limitation, but csn be provided if anyone is particularly interested.

I think, now that the remaining time could best be devoted to attempting to answer any of your questions if there are any.

TABLE 1: Diagnostic Testing of Experimental FAE Warheads

Type of Test	Warhead											
	1	2	3	4	5	6	7*	8	9	10	11	12
Temperature Shock (-65 degrees - +165 degrees F)		P	P	P	P	P						
40-Foot Drop					P_1							
Incremental Drop (2 & 6 ft.)	P	P										
Shock Test						P						
Vibration Test (40 degrees F)								F_1				
Temperature & Humidity (10 cycles)									P	P		
Bullet Impact									T_1	T_2		
Fast Cookoff											T_4	
Slow Cookoff												T_3

* No. 7 was not vibrated due to failure of No. 8.

P - Unit passed test.

T - Success criteria not defined.

F - Unit failed test.

T_1 - Fuel cloud ignited externally, burned for 8-minutes then cloud detonator cookoff.

T_2 - 20MM impact, no ignition of fuel.

T_3 - Developed leak of fuel pressure of 225 psi at approximately 190 degrees F.

T_4 - First reaction at 1-minute, large reaction at 2-minutes 27-seconds.

P_1 - Fuel spilled, but did not ignite.

F_1 - Fuel leak at cloud detonator weldment after 1st cycle.

TABLE 2: Environmental Evsluation Tests, FAE P1 Wespons

Type of Test	Wespons								
	1	2	3	4	5	6	7	8	9
Transportation Vibration[a]	P	P	P						
Humidity[b]	P	F_1	F_2						
Aircraft Vibration[c]	R	N	N						
Rain				P	P	P			
Dust[b]				P	P	P			
Fungus				F_3	F_3	P			
Salt Fog				C	C	P			
Leakage				F_4	C	P			
High Tempersture Stge[b]							P	P	P
Low Temperature Stge[d]							P	P	P
Temperature Shock							P	P	P
Sunshine							P	P	P
Shock (Drop Test)							P	P	P

P Test unit assigned, passed test.

F Test Unit assigned, failed (see below).

N Test not conducted due to failure earlier in test sequence.

C Test sequence continued after failing earlier test sequence.

a Vibration imput curve from MIL-STD-810B, Curve AB of Fig. 514-6, Method 514.

b Upper temperature limit (130 degrees F) as defined by NWC TP 4480.

c Vibration imput curve modified from MIL-STD-810B, to correspond with sctual measured vibrstion data.

d Lower temperature limit -20 degrees F.

R Rubber burster charge retainin plugs slipped.

TABLE 2: (Cont'd)

F_1 Fuel vapor leaked from bombs into dispenser and caused leak indicator to turn red. Vapor concentration inside dispenser above 3.5%.

F_2 Same as F_1 but indicated leakage 0.5%.

F_3 Fuel leak indicators red. Less than .01% when leak samples obtained at the conclusion of the Salt Fog Test.

F_4 Unit considered failed. Retained 4.7-lbs of water.

TABLE 3: Safety Evaluation Tests, FAE P1 Weapons and Warheads

Type of Test	Complete FAE Weapons														All-up Warheads	
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24-32	33-37
28-Day Temp/ Humidity	P	P	F_1													
Transportation Vibration	P	P	N													
Salt Spray	P	P	N													
Aircraft Vibration	F_2	F_3	N													
4-Day Temp/ Humidity	F_4	F_5	N													
2-Foot Drop				P	P	P										
40-Foot Drop				P	P	P										
Fast Cookoff							P	P								
Slow Cookoff									W_1	W_2						
Propagation											P	P				
Catapult and Arrested Ldg													P			
Accidental Release														T		
Bullet Impact															T	
Cloud Detonator																T

P Test unit assigned, passed test.

F Test unit assigned, failed (See below).

N Test not conducted due to failure earlier in test sequence.

W Unit did not meet WR-50 requirements.

T Success criteria not defined, see test report results.

F_1 Two bombs in TM-12 ruptured during test.

F_2 No. 10 completed vibration test (24 hours), but had developed 3 cracks in the dispenser strongback after completing 16 hours of vibration.

F_3 No. 11 dispenser cracked after 12 hours of vibration. After 15 hours and 30 minutes of vibration, strongback almost severed from dispenser.

TABLE 3: (Cont'd)

F_4 No. 10 bombs leaked fuel.

F_5 No. 11 bombs leaked fuel.

W_1 Reaction occurred at maximum temperature of 235 degrees F.

W_2 A fireball reaction occurred at a maximum temperature at 250 degrees F.

TABLE 4: Environmental and Safety Tests of Pilot Production Model CBU-55/B Weapons

Environmental Tests	Weapons											
	1	2	3	4	5	6	7	8	9	10	11	12
Transportation Vibration		P		P		P		P				
High Temperature Storage			P	P		P	P	P				
Temperature Shock					P	P	P	P				
Aircraft Vibration	P			P	P			P				
Salt Fog	P	P					P	P				
Dust	P		P			P		P				
Safety Tests												
28-Day Temperature/ Humidity									P	P		
Transportation Vibration									P	P	P	
Aircraft Vibration									1	P	P	
4-Day Temperature/ Humidity									N	$1_{(1)}$	P	P
6-Foot Drop									N	P	P	P

NOTE: P - Designates that the weapon passed the test.

1 - Indicates that an interpretation is necessary since the weapon showed a fuel leak greater than 3.5% inside the dispenser after 16-hours and 12-minutes of vibration.

N - Designates that the test was not conducted.

$1_{(1)}$ - Indicates that an interpretation is necessary since the weapon showed a fuel leak of 0.5% after the 4-Day Temperature/Humidity Tests.

ENVIRONMENTAL CONDITION REPORT FOR
NUMBERED DEEP WATER MUNITIONS DUMP SITES

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I. BACKGROUND

In April 1971, the Chief of Naval Operations tasked the Oceanographer of the Navy to prepare a comprehensive environmental condition report for past numbered DWD operations involving conventional munitions cargos. In addition, recommended criteria for future DWD site selection and monitoring programs were requested. Of the nineteen past DWD operations conducted, four contained chemical ordnance wastes, and fifteen contained conventional munitions only.

II. PLANNING THE DWD ENVIRONMENTAL PROGRAM

Several Navy operational and staff commands, three Navy laboratories, scientists under contract from three major universities and representatives of the National Academies of Sciences and Engineering participated in the selection of representative past DWD sites and in the development of a sampling plan. Senior credentialed researchers from the fields of chemistry, biology, physics and geology participated as principal investigators during data collection analysis and reporting phases.

A literature review to amass known environmental and operational data surrounding all past DWD operations was conducted. Criteria evaluated in the selection of representative past DWD sites included nature of the DWD cargo, confidence in the scuttling position, age of the event, post scuttling occurrences, depth, physical, chemical and biological regime, and bottom topography. Two DWD areas were selected as representative survey

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sites which reflected the spectrum of past DWD activities involving conventional munitions cargos. Area G off Cape Flattery, Washington was the primary choice for a site where cargo detonation had occurred. Five DWD operations had been conducted in this area over a thirteen month period ending in September of 1970. All five cargos detonated during scuttling, representing the highest level of environmental stress at any past conventional disposal site. Area E, east-southeast of Charleston, South Carolina, the site of DWD IX, was selected as the representative undetonated site.

A suite of environmental parameters was selected for measurement at each representative DWD area with the following goals in mind. The benthic biota would be evaluated to detect any catastrophic impact upon their types and numbers and to detect any differences in fauna between reference stations and the DWD sites. Biological specimens would also be examined for concentrations of heavy metals and for uptake of munition compounds. The sediment regime would be evaluated to determine levels of organic carbon and nitrogen, texture, properties relating to debris burial, and the presence of heavy metals and munition products. The chemical properties of the water mass would be evaluated for dissolved oxygen concentration, nutrients, heavy metal and munition product levels. The stability and circulation of the water mass were to be evaluated through measurements of temperature, salinity, near bottom vertical water transport, and moored current meter arrays. In this manner a total picture of each representative DWD area for comparison to nearby reference sites and values previously reported in the literature would be available.

III. WEST COAST REPRESENTATIVE DWD SITE EVALUATION (CARGOS DETONATED)

Search operations conducted in July 1970 by Scripps Institution of Oceanography from USNS DESTEIGUER (T-AGOR 12) were highly successful, culminating in the relocation of the debris of all five DWD hulks scuttled in Area G. In over 1,000 photographs taken, the debris patches were shown to be nearly circular and well defined. The hulks and cargos had been reduced to rubble by the detonations which occurred during scuttling. No cratering of the sea floor was detected. Many types of benthic organisms were observed within and outside the debris fields. The geographical position of the debris area was marked with acoustic transponders to facilitate precise relocation during the follow-on environmental survey.

In September 1971, the follow-on environmental assessment survey of DWD Area G was conducted from the USNS DESTEIGUER. Five major stations were occupied: one in the DWD area, two adjacent to the area, and two reference stations twenty miles to the north and south of the area. Data were collected on sediment properties, water mass characteristics, bottom biological populations and levels of possible contaminants. In addition, current meter arrays and radon measurements were made to evaluate the horizontal and vertical circulation dynamics of the area. Following is a summary of observed environmental conditions.

A. Sediments.

The sediments at DWD Area G and reference stations are typical for this geographic area. There appear to be no anomalies in organic carbon and organic nitrogen levels which would indicate a significant contribution

of nitrogen due to particulate explosive residue. All mineralogical and physical parameters sampled appear within ranges previously reported in the scientific literature.

B. Water Mass Characteristics.

Temperature, salinity and density profiles for the DWD Area G are well within the envelopes reported in the historical literature and appear completely normal. Oxygen profile data fall within the expected values for this area. No apparent long lived depletion of dissolved oxygen has resulted from the past DWD detonations at Area G. Nutrient levels observed are within the historical range of concentrations based on extrapolated data from shallower depths. Past DWD operations at Area G appear to have caused no anomalies in nutrient levels.

C. Circulation Dynamics.

The water mass in Area G is vertically stable. Bottom currents are low in velocity but appear sufficient to insure dilution of any soluble products generated by the DWD debris field. Measurements of vertical transport in the near bottom waters show a strong boundary layer between 60 and 80 meters above the bottom through which vertical transport is greatly restricted. Therefore, any possible contamination resulting from DWD residues in Area G should be essentially confined to the bottom 80 meters of the water column and should not interact with the surface food web.

D. Biological Investigations.

Although lack of historical information precludes a full characterization of the normal state of the benthic fauna in the northeast Pacific basin, the sampling program conducted using photography, cores,

grabs, and trawls shows the fauna at the DWD site to be essentially similar in quality and quantity to that sampled at outlying reference stations. Within the limits of present knowledge of deep sea benthic communities and the number of samples collected, the infauna, epifauna, bottom fish and bacterial populations appeared normal at the time of sampling. It must be noted, however, that sufficient time had elapsed between the final DWD operation in Area G and the environmental survey to allow for repopulation or reinvasion of the area had any reduction in the biota occurred in the past. The most important result is that there appears to have been no irreversible wastage of the benthic fauna due to the past DWD operations in Area G.

E. Levels of Contamination.

No evidence of contamination of the sediment, benthic fauna or near bottom water samples in Area G by major munitions products was found within the limits of detection. Under precise laboratory calibration of standards, the limits of analytical detection for TNT, RDX and Tetryl were determined to be 2, 5, and 20 parts per trillion respectively for sea water and 47, 123, and 740 parts per trillion respectively for sediment and faunal samples. For ammonium perchlorate, a limit of detection of 0.1 part per million was determined for water, sediment and faunal samples.

Considering possible contamination by heavy metals, results indicate that there has been no contamination of mercury near the dump site; however, levels of lead in the sediment near the dump site are an order of magnitude higher than at nearby reference stations. Corresponding

increases in lead values were not observed in faunal tissue or near bottom water samples. Levels observed were in the parts per million or parts per billion range, and the significance of these very minute levels is questionable.

IV. EAST COAST REPRESENTATIVE DWD SITE EVALUATION (CARGO UNDETONATED)

In November - December 1971 a combined search operation and environmental survey was conducted from USNS MIZAR (T-AGOR 11) in DWD Area E, the site of the DWD IX disposal operation. The search task involved location of the single intact hulk of the SS MONAHAN scuttled in 1967 in approximately 2,315 meters of water. Upon precise location of the hulk an environmental survey similar to that conducted on the West Coast in Area G was planned.

Based on the last recorded position of the MONAHAN, 31° 40'N and 76° 56'W, an extensive sea floor search was conducted using side looking sonar, magnetometer and photography. The best datum available was used as the center for two concentric search circles of five and ten mile diameters. The smaller of these circles was covered by the deep towed instrument vehicle until a search effectiveness probability (SEP) of from 0.992 to 0.998 was attained. The area between the five and ten mile diameter circles was searched to an SEP of 0.41. The total area scanned by side looking sonar was 4,725 million square feet. Some acoustic and magnetic contacts were gained, but no photographic evidence of the intact hulk of the MONAHAN was obtained. Search photography located scattered ordnance and ordnance related debris on the sea floor. The area had, however, been used as an over-the-side disposal site prior to the scuttling of DWD IX.

A bottom biological trawl run made during the survey passed between the largest magnetic anomaly recorded in the search area and several observed acoustic contacts. Upon retrieval, this trawl contained a kilogram of rusted metal fragments encrusted with barnacles. The metal was later identified as mild carbon steel similar to that used in the hull plating of the MONAHAN, while the barnacles were identified as obligate shallow water forms common to the area where the MONAHAN had been stored prior to use as a DWD hulk. Identical barnacles were recovered from the former hulk anchorage site. The trend of this evidence indicates that the DWD IX hulk is located on or very close to the track of the biological trawl.

In any event, unexploded ordnance is now resting on the sea floor in the DWD IX area, and the examination of ocean parameters and environmental measurements made during the MIZAR survey does record their present effect on the environment.

Most of the scheduled survey period of the USNS MIZAR in Area E was devoted to the intensive search operation, and only a small amount of the originally planned environmental survey was conducted. However, environmental samples were taken at several stations both inside and outside the charted disposal area, and biological grabs and trawl runs were conducted. In addition, throughout the search operation bottom photographs were continually analyzed, and the distribution of all observable fauna was plotted. Following is a summary of observed environmental conditions.

A. Sediments.

The sediments observed at DWD Area E were principally mixtures of foraminiferal and pteropod ooze. As may be expected from sediment samples near the base of the continental slope, some variation in texture was observed. All mineralogical and physical parameters measured appear within ranges previously reported in the scientific literature.

B. Water Mass Characteristics.

Temperature, salinity and density profiles for the DWD Area E are well within the envelopes reported in the historical literature and appear completely normal. The past DWD operation and over-the-side disposal of ordnance waste in the area appear to have caused no anomalies in near bottom oxygen or nutrient levels. The water mass in Area E is vertically stable. No density inversions were evident in the water column below the mixed layer. The vertical stability associated with the density structure prevents exchange of surface and bottom waters.

C. Biological Investigations.

Biological investigations were conducted using photoanalysis, grab type samplers and bottom trawls. The observed epifaunal benthos was homogeneous throughout Area E. No identifiable differences existed in numbers or species of benthic organisms occurring inside or outside the charted dump site. Benthic biomass values obtained in Area E appear consistent with the available historical data for the temperate northwest Atlantic. High species diversity index values obtained indicated that many species exist throughout the area, thus suggesting a stable environment. Observed evidence indicates the benthic fauna at Area E is presently in good health. The fauna observed and collected are re-

stricted to the deep ocean and do not occur in shallower faunal zones. Chances are remote that benthic fauna from Area E would be incorporated into the food web of marine organisms commercially harvested.

D. Levels of Contamination.

No evidence of contamination of the sediment, benthic fauna or near bottom water samples collected in Area E by major munitions products was found within the limits of detection. A limited number of measurements on sediment, faunal and water samples was made to determine levels of lead and mercury. None of the values observed indicated lead or mercury contamination. Sufficient data was not obtained to evaluate heavy metal levels on a distributional basis.

V. FUTURE SITE SELECTION

From analyses of past DWD operations and environmental data collected during this program, twenty characteristics listed below have been identified which would appear to define an optimal potential DWD site. These optimal characteristics minimize potential loss or irreversible commitment of both living and non-living resources of any area considered for future DWD operations, allow for comprehensive understanding of the physical, chemical and biological regime at any potential site so that environmental impact can be predicted, and also consider operational logistics and safety and potential future deep ocean search requirements.

OPTIMAL CHARACTERISTIC	IMPACT
No actual or potential mineral or petroleum resources	Minimizes potential resource lose due to presence of undetonated hulk or a debris field.
Not in an area of man-made deep ocean engineering systems	Minimizes possible impact on submarine cables or other installed systems.
No fisheries or sport fisheries utilization	Minimizes potential direct impact on commercially important fish or marine mammal species.
Deep water in excess of 7,000 feet	Defines area seaward of continental shelf and slope; minimizes impact on nearshore fisheries; minimizes hazard to man.
Outside of major migratory routes of marine fish or mammals, temporally or spatially	Minimizes potential direct impact of detonation in surface or midwater on migratory species.
Removed from primary food web or major utilized species	Minimizes potential indirect impact on commercially important fish or marine mammal species.
Documented stable bottom biota	Provides for pre-dump predictions of potential impact on bottom biota.
No previous stress from other types of ocean dumping (sludge, spoils, industrial wastes)	Eliminates other obvious man-made stresses on the environment; provides for maximum biological community capability for recovery; allows better prediction of chemical interactions.
Documented surface, midwater and bottom currents	Insures predictable mixing and dilution of corrosion or detonation products; provides for resupply of dissolved gases into area; insures normal larval recruitment into any stressed areas.
Vertically stable water column (all seasons)	Limits interaction of decomposition products of hulk or debris with the surface food web.

OPTIMAL CHARACTERISTIC	IMPACT
Documented deep ocean temperature and salinity profiles	Allows predictions of vertical mixing expected and predictions of rates of corrosion.
Ample oxygen present to support life	Provides oxygen replacement capability to supply any detonation demands; provides oxygen to sustain populations in recovery from any potential impact; aids in prediction of rates of corrosion and fate of solution products of cargo or detonation products.
Close to loading depot	Minimizes transit time to dump area, thus cutting costs and minimizing safety problems during transit.
Favorable climatic conditions for period of transit and operations	Decreases potential heavy weather interference with transit and on-site operations.
Outside of maritime traffic routes	Minimizes any potential for surface traffic during scuttling.
Outside of submerged transit lanes	Minimizes potential hazard to submerged navigation; minimizes future restrictions on search and monitoring operations.
Good electronic NAVAID coverage by at least two systems	Provides for precise location of the scuttling datum.
Firm, consolidated sediment	Minimizes hulk or debris field burial, thus providing better potential target for search mission.
Low microrelief	Minimizes interference of sea floor topography with possible search mission.
Isolated from areas of multiple bottom contacts	Reduces potential interfering targets for search mission.

By assigning a maximum of five points to each of the twenty criteria discussed above, a potential or past disposal site can be rated on a 0 - 100 point scale relative to the optimal criteria. Without

weighting any characteristic, a total point score within the 80 to 100 point range would indicate a good potential DWD site. Areas are available which would meet these criteria. Two examples are past DWD Areas G and F.

VI. FUTURE MONITORING EFFORTS AT PAST DWD SITES

Since 1967, efforts in relocation and/or environmental measurements have been made at six of the ten past DWD areas containing 19 hulks or their debris. Seven of the 19 hulks or debris fields have been precisely located, and there is strong evidence that an eighth, DWD IX, has been very closely approached during surveys. Search and survey operations are scheduled for April - July 1972 which should pinpoint and examine the four hulks or debris fields in DWD Area A. If successful, these operations would raise the number of located and examined DWD residues to 12 out of 19. Investigated areas include both sites where detonation of DWD cargos did and did not occur.

Even a cautious review of the data collected to date does not reveal striking changes in the deep ocean environment where the past DWD hulks or their debris now reside. To engage in further search and environmental surveys of the remaining five DWD areas could require resources in excess of two million dollars and commitment of over 250 on-station days of major oceanographic platform time. The return for this large resource commitment in terms of additional scientific understanding of past DWD operations would probably be quite small. A more sensible extention of the considerable effort expended to date would be to resurvey DWD Area G five years after the major post-dump survey just completed. The five cargos detonated in this area represent the highest

level of environmental stress of any past DWD operation. A five year resurvey of this area where baseline data now exists should serve to investigate long range effects not now discernible. The total resource commitment required should be under 100,000 dollars and require about two weeks of platform support.

VII. FUTURE DWD ASSESSMENT PROGRAMS

A draft and final environmental impact statement will be required for any future DWD operation. If the environment at the proposed site is not well documented, a predisposal survey is recommended and may cut the cost of follow-on monitoring requirements. During any future disposal operation, plans should be made to conduct environmental evaluations during the scuttling and immediate post scuttling period. The degree of on site evaluation required during sinking will be directly linked to the aspect of hulk detonation, and unless non-detonation can be positively assured, cargo detonation should be planned on and devices used to control it. In any future operation, precise fixing of the hulk location should be stressed to reduce or eliminate follow-on expenditures for search and relocation operations. For any initial future DWD operation it is recommended that an environmental assessment survey be conducted one year after scuttling. Additional monitoring efforts, if necessary, could be determined based on the results of this follow-up investigation.

VIII. SCIENTIFIC FRINGE BENEFITS

The past DWD environmental program has fostered several interesting and possibly significant developments. Surveys of near bottom vertical transport in DWD Area G represent the first seasonal resurvey of these parameters using the Radon (222) technique. Repeatability of results between seasons was quite encouraging. The intense biological sampling in this area may contribute to a significant increase in the understanding of benthic fauna in the Cascadia Basin. Several specimens believed new to science were collected. A good body of data was also added to existing knowledge of deep ocean currents in the northeast Pacific. New analytical techniques were developed for analysis of munition product levels in ocean sediments and faunal tissue. In the surveys conducted at Area E, additional specimens were collected thought to be new to science. In addition, results of photoanalysis of benthic fauna were entered into a newly developed computer program for biological analyses and represent an initial biological data bank against which future data on deep ocean effects of DWD operations can be compared. During the survey of DWD Area F the first successful positive position control and photographic record of a deep ocean trawl operating on the sea floor was obtained. A potential now exists to truly quantify deep sea trawling and add a large measure to present understanding of the deep sea biota.

IX. OVERVIEW

While all questions about the environmental effects of past DWD operations could not be answered by the present program, the results indicate that this disposal method does not do significant irreversible damage to the deep ocean environment. This tool should be evaluated carefully against the potential hazards, costs and ground, air and stream pollution which may be connected with future terrestrial ordnance disposal systems. With care in site selection and intensive operational control DWD is a viable and environmentally defendable alternative method of ordnance disposal.

HAZARDS ANALYSIS OF THE DEBAGGING OPERATION FOR OBSOLETE GUN PROPELLANT

J. J. Swatosh, Jr., H. S. Napadensky, and D. R. Morita
IIT Research Institute
Chicago, Illinois

A hazards analysis was performed on a system designed at Badger Army Ammunition Plant for debagging obsolete M-19 propelling charges, in order to recycle the M-6 propellant in the bags. In the analysis, all operations in the process were identified. The sensitivity of the aged M-6 propellant was determined and compared with new material. The failure mode and effects hazards analysis led to a list of recommendations to maximize the safe operation of the process.

This presentation discussed failure mode and effect(s)-type safety analyses and illustrated its application to the problem of reclaiming aged ordnance items.

Details of this investigation appear in a report entitled, "M19 Propellant Charge Debag Operation Hazards Analysis," 10 December 1971, by Napadensky, H.S., et al. Additional information on this work may be obtained from Olin Energy Systems Division, Badger Army Ammunition Plant, Baraboo, Wisconsin 53913.

DEMOLITION BY BURNING OF BATCH TNT PRODUCTION LINES

Franklin J. Forsythe
Joliet Army Ammunition Plant
Joliet, Illinois

Introduction: Under an Army modernization program the demolition of two (2) Batch TNT production lines and the construction of three (3) new continuous process lines on the same site was scheduled for JAAP. It is hoped that our subsequent experience in the destruction of explosives operating facilities and the eventual reuse of the land they occupied will be of interest and use to you.

SLIDE 1 on (Plant Sign)

Joliet AAP is wholly owned by the US Government - property, buildings and equipment - and operated by Uniroyal, Inc. under contract let by the Department of Defense through the Ammunition Procurement and Supply Agency (APSA). It is located approximately 8 miles south of Joliet, Illinois on US Rt. 53.

The basic mission of JAAP is to safely produce high explosives of the type used in conventional artillery projectiles and aerial bombs, and to load, assemble and package certain classes of projectiles and bombs. Currently, both TNT and Tetryl are being manufactured and 105mm artillery rounds are being loaded.

SLIDE 1 off

SLIDE 2 on (Panorama of TNT area)

This is a view of our TNT production area. The buildings shown constitute twelve (12) operating lines of five (5) process buildings each with a common nail house (packing & shipping facility) servicing every two lines. In this batch process toluene, a petroleum derivative, is mixed with nitric acid in three separate buildings, the mono, bi, and tri-houses.

Sulfuric acid is introduced as a drying agent during each nitration. This tri-nitrated material (crude Trinitrotoluene) is then drooped by gravitational feed to a wash house for purification, and flaking. Boxes of pure TNT are then moved by conveyor to the nail house where they are sealed and shipped.

Each line also has a fume recovery building which reclaims waste acids.

SLIDE 2 off

SLIDE 3 on (Close-up of TNT lines 11 & 12 and new construction site)

This close-up view of operating lines 11 & 12, those marked for destruction, also indicates a large clear area to the left. Three additional continuous process TNT lines were to be constructed in this area (work now nearing completion.) Since this construction would be in progress during demolition operations, it was mandatory to maintain intraline separation between the two work sites. This same quantity distance was necessary between the demolition site and adjacent batch process lines in operation.

SLIDE 3 off

SLIDE 4 on (Schematic of new lines, Demolition area & proposed lines & TNT area 5, lines 9 & 10)

A schematic indicates how the area will appear once the entire modernization program is completed. To the left we have the three (3) lines which are now under construction. In the center are the lines to be built on the demolition site and on the right are the existing 9 & 10 batch lines. As you can see there are far fewer buildings in the new process areas than in the batch production lines. This reflects the basic difference between the CIL continuous process and the batch method.

Each continuous nitration line of the new process requires only two main production buildings, as compared with five for the batch process. One of these is the nitration and purification building; the other is the finishing building. In this process toluene is being continuously nitrated and passed through purification processes to become TNT. In the older process only a limited quantity or batch of toluene could be nitrated at any one time.

SLIDE 4 off

Once the decision was made to locate three of the proposed six CIL lines on land which was being used for TNT production, our work began. We had to establish a safe and economical method by which existing buildings and equipment could be most effectively demolished and the area prepared for safe excavation and construction.

After much study and deliberation it was decided that the best method of demolition would be burning in place. We chose this method, as opposed to dismantling, because it minimized the possibility of personnel injury due to explosion. If explosions did occur during the burning, there would be no possibility of injury or death.

SLIDE 5 on (Regulations used)

We then began the approval process by preparing a "Safety Submission" using these regulations as our guides:

AMCR 385-100, AMC Safety Manual
AMCR 385-1, Safety Responsibilities & Program Requirements
MUCOMR 385-23, Decontamination & Disposal
APSA Pam 235-1, Maintenance, Layaway & Decontamination of Facilities
DLSC Bulletin, 20 Feb 69, Explosive & Acid Contaminated Contractor Inventory

This "Safety Submission" had to include as a minimum: Description of facility,

land and equipment involved, to include: type and degree of contamination, method of decontamination, method of diamantling and disposal action.

SLIDE 5 off

SLIDE 6 on (Agencies Involved)

This "Safety Submission" was drafted by Uniroyal, Inc. with the technical guidance of our COR Safety Office. Once we concurred in the finalized submission and related Standing Operating Procedure, the package was forwarded to the Ammunition Procurement a d Supply Agency for their review and comments. It was then ro ted to Headquarters, Munitions Command for final approval.

Of course the approval process did not flow as smoothly and rapidly as might be suggested. Work on the submission began in late 1971 and final approval was not received until 17 Mar 72. The interim period was filled with telephone conversations, comments, revisions and interpretations which insured that the final procedure was safe in every way.

SLIDE 6 off

SLIDE 7 on (Final Approval)

The receipt of approval marked the beginning of yet another pre-work process. A project package was then prepared and sent to the Omaha District of the Corps of Engineers. The Corps put the project out for bid and a private contractor was selected to accomplish the actual work under Corps supervision. The approved procedure was incorporated into the contract specifications. Work began in August 72 and was completed in approx. 6 weeks.

SLIDE 7 off

The procedure in its final form had to take into account a number of Safety

problems and how to effectively deal with them:

SLIDE 8

An unknown history of line operations from 1940 - 1945.

SLIDE 9

The very real possibility of buried contaminated drains and unknown underground explosive deposits.

SLIDE 10

Weather conditions immediately before and during the times of burn.

SLIDE 11

Unknown Explosive Deposits remaining in process lines.

SLIDE 12

The danger of power lines above ground in the area.

SLIDE 13

Process acid lines running through the demolition site.

SLIDE 14

And the problem of air pollution in relation to local civilian populations.

SLIDE 14 off

The extent of these problems and just how they were handled should be evident in the films taken throughout the actual demolition work period.

DEMOLITION OF BATCH TNT LINES

Our film begins with a view of the two TNT lines marked for demolition. These lines were originally built in 1940 for the purpose of military support during World War II. This initial period of oparation, 1940-1945 presented us with our first problem, the history of this operation was almost totally unknown. We did not feel that there was any significant contamination left, but doubt remained as to the exact location of underground drains and transfer pipes which had not been used in over twenty-five years. If there had been any important spills or mass contaminations it was completely unknown. Thus, we had to proceed on the basis that contamination did exist in the area.

Both lines were deactivatad in February of 1970. At that time all equipment and buildings were decontaminated to a 3X (XXX) condition.

Since each building in the complax held possibilities of contamination due to overflows, drownings and the accumulation of loose explosive dust, elaborate preparations had to precede actual demolition. All salvaged equipment inside and outside of buildings had to be removed and decontaminated, by hot watar and steam. Exterior piping, including TNT transfer lines, was disconnected at flanges and accumulated for flashing.

Barricades also presented another critical situation. Tri-oil transfer lines passing through these barricades were disconnected and the timber sections of the barricade cut down to grade level below these pipes. The earth fill was than examined for possible solidified explosive. If explosive was found, it was to be carefully removed and transported to our Burning Ground for disposal.

Finally, the conveyors on each line were removed and accumulated for burning with one of the two lines. This aided in the control of the fire once it was ignited.

Uniroyal, Inc. assisted in the rerouting of all overhead electrical lines and acid transfer piping.

Once we were reasonably sure that serious contamination had been eliminated, the buildings were prepared for burning. Transite sheeting, inside, was broken to about four feet above the floor level on each floor, and outside asbestos sections were prepared similarly. Sections of ceilings, roofs, and floors were broken out to create drafts for more effective burning. Straw was then placed in the broken sections of walls and throughout each building. This combustible was sprayed with diesel oil and tires were distributed throughout the buildings. In all, 200 bales of straw, 200 tires and 5,000 gallons of #2 diesel oil were used.

When all preparations were made, trains of oil soaked straw leading to each building were ignited by fuzeas similar to roadside flares.

Obviously the actual starting of the burn was also governed by strict procedures. Weather was an important controlling factor. Burning could only be done during low wind velocity (under 10 mph) and preferably after or during a light rain. Because of this the final decision as to whether to go or not go was not made until 30 minutes prior to the scheduled ignition time. We also could not begin burning until after 4:00 PM, at which time adjacent operating lines could be shut down and all personnel in nearby construction areas would be absent.

One day prior to scheduled burns, we notified State and Federal Pollution Control Offices, local Fire and Police Departments, Joliet AAP personnel and military residences in the immediate area.

The final decision to burn was made by COR representatives in close co-ordination with Uniroyal Production and Safety personnel.

Each line was burned at a separate time, 10 days apart, to allow preparation for burning and for beginning removal of the burned line. Each straw train was ignited separately at a given signal, and the individuals accomplishing this were evacuated by truck to a safe area. A spotter was stationed at each corner of a rectangle, 1,000 feet away from and around the burning site to check for flying embers. Fire trucks were standing by, also at a distance of 1,000 feet.

The fires began smoothly and burned well. It took approximately two hours for the buildings to burn completely. All of the conveyors from both lines were accumulated at the nail house and burned during this second fire.

After the initial two hour burn, each fire continued to smolder throughout the night. A spotter remained with the area until morning, and frequent checks by Safety and Fire personnel were made.

The combustible portions of the buildings were consumed and the steel superstructures became visible. Surprisingly, much of this steel and the equipment suspended from it remained in place. Concrete slab floors also remained and continued to support the large tanks. In both fires, only three or four small explosions occurred. They were certainly not high order detonstions, but more like shotgun blasts. None was large enough to change smoke direction or cause flying embers. The only evidence was the sound. Thus, we surmised that the source or location of the blasts was the wash house. A small deposit of explosive in a valve or pipe could have been missed when the lines were deactivated.

After e 48 hour wetch period to allow all fires to burn out and insure that the possibility of explosions wes at a minimum, e thorough inspection of the area was made by Safety and Production personnel. After deciding that the area was again safe, the contractor was allowed to re-enter the site to cut piping and sort the debris with crane and magnet. All contamination had of course been removed due to the extreme heat of the fires.

To dismantle the remaining structures, the contractor connected cables to the upper portions of the steel frames and undercut the girders with torches. Then by pulling the cables by crane, the steel frames easily crumbled. This system avoided subjecting any contractor employee to the hazard of dismantling the structures from above ground level. The materiel was then cut into smaller sections and removed.

When the majority of the debris had been removed and all that was left was the excavation of foundations, tanks and piping, the dangers of the unknown came into play. All had gone excellently up to this stage with even fewer problems than we had anticipated. The contractor and his personnel were briefed thoroughly on the procedures to follow if in the course of excavation explosive deposits were unearthed. We felt that he had a thorough understanding of the situation and an appreciation of the hazard. We soon found out that we were right.

A few days after the beginning of excavation, a back-hoe, working along a sanitary sewage drain, uncovered large chunks of solidified TNT. Work was immediately halted, and COR Safety was notified. After a thorough inspection of the area, the deposit was completely unearthed and removed

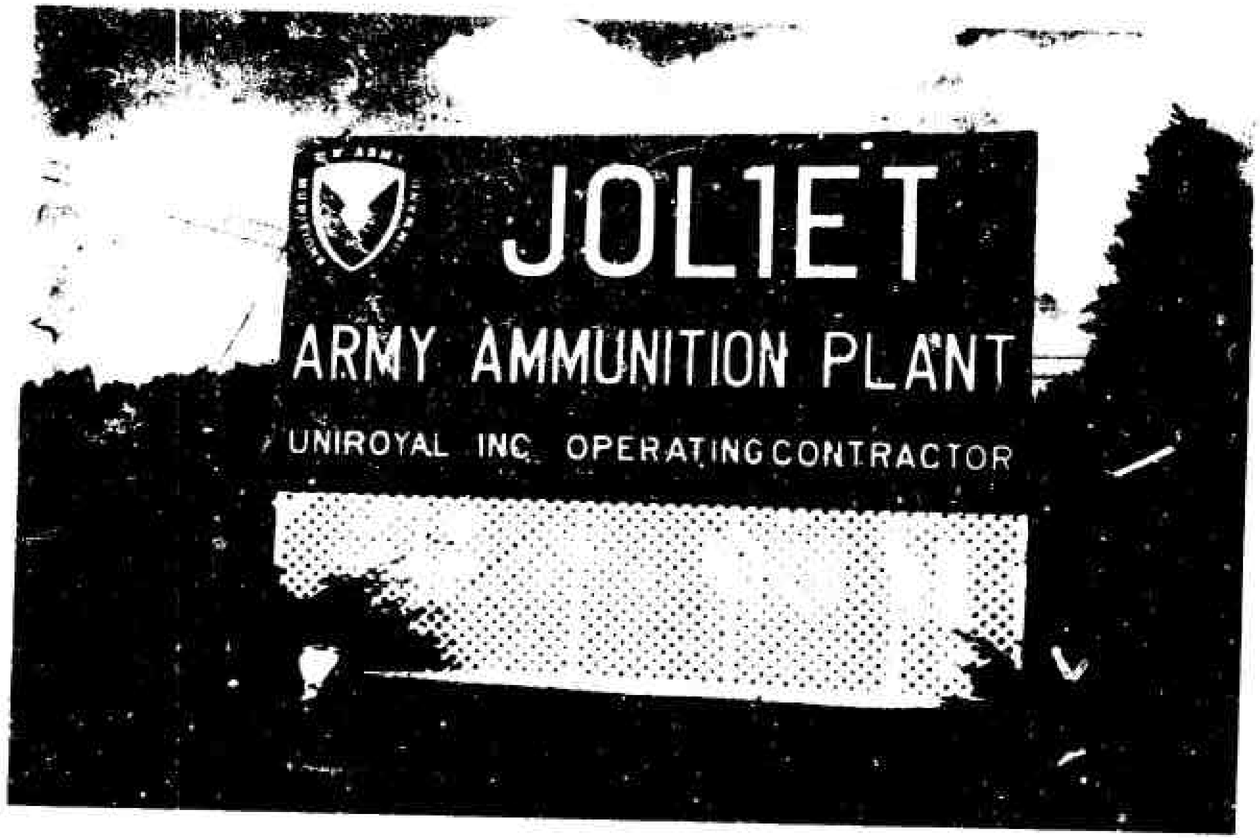
to the Burning Ground. A TNT deposit in this specific area could never be completely explained; it was just a good example of the hazards of an incomplete operational history. But the contractor had proceeded correctly and what could have been a problem was easily resolved.

Before excavation activities were completed, a pool of acid was uncovered, another explosive deposit found and contaminated pipes unearthed. Work was immediately halted and a neutralizer was added to the acid, the contaminated pipes were carefully dug up with surrounding earth and flashed and the TNT deposits were located and destroyed.

Approximately six weeks from the contractor entrance date, we had demolished two complete TNT production lines, removed the debris and prepared the land for the construction of three new modern lines.

Our new CIL continuous process TNT lines are now nearing completion on a site adjacent to the demolition area. They are identical to the lines being constructed to replace those that were burned. Both operating buildings are earth covered. Nitration and purification is accomplished in the first building. The resulting TNT slurry is then dropped by gravity feed to the finishing building where it is dryed and flaked. The conveyors then carry boxes of flaked TNT to a shipping building for loading onto railcars or trucks. Each line has a capacity of 100,000 pounds of TNT per day.

By putting operational safety foremost in every phase of the project, by working in close coordination with all agencies and contractors involved and by maintaining day to day surveillance of work progress, we saw a potentially dangerous project through to completion without incident.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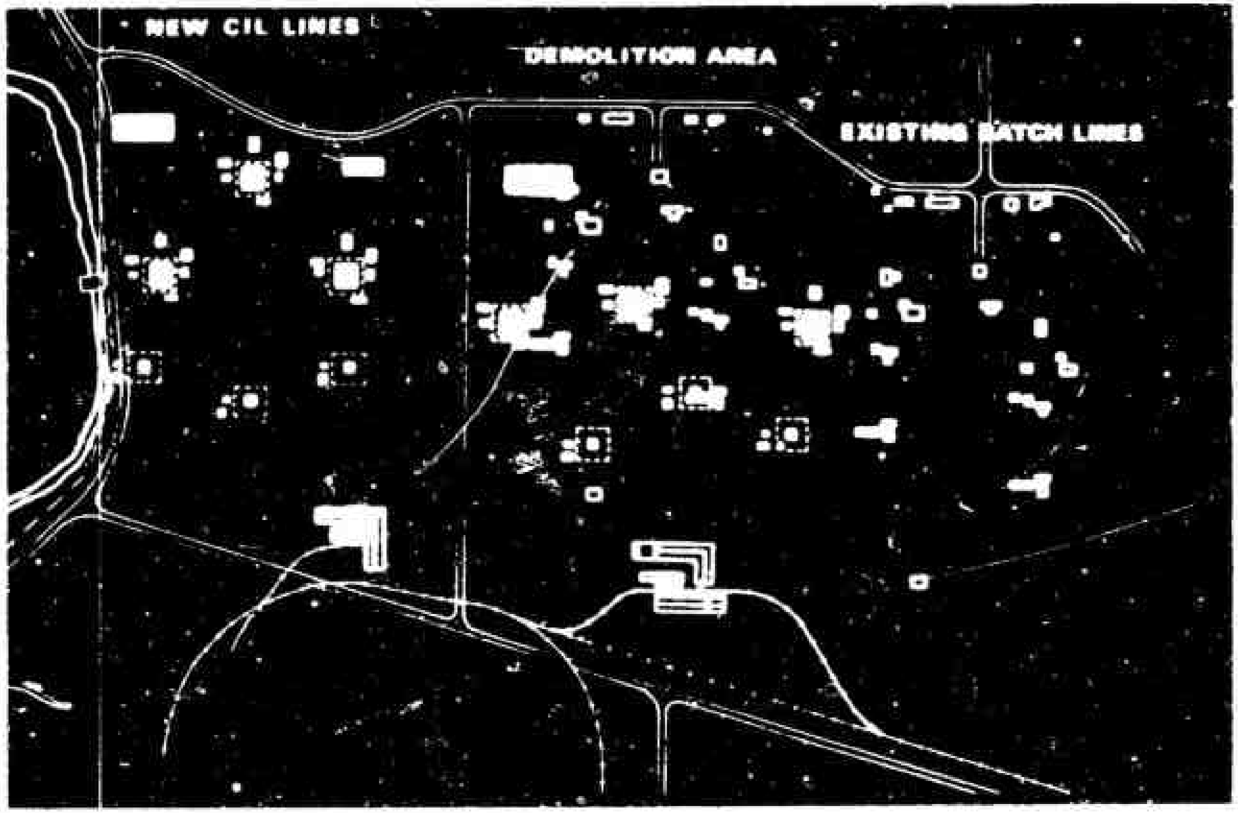
ARMY AMMUNITION PLANT
UNIROYAL INC. OPERATING CONTRACTOR


NEW CIL LINES
DEMOLITION AREA
EXISTING BATCH LINES

REGULATIONS INVOLVED

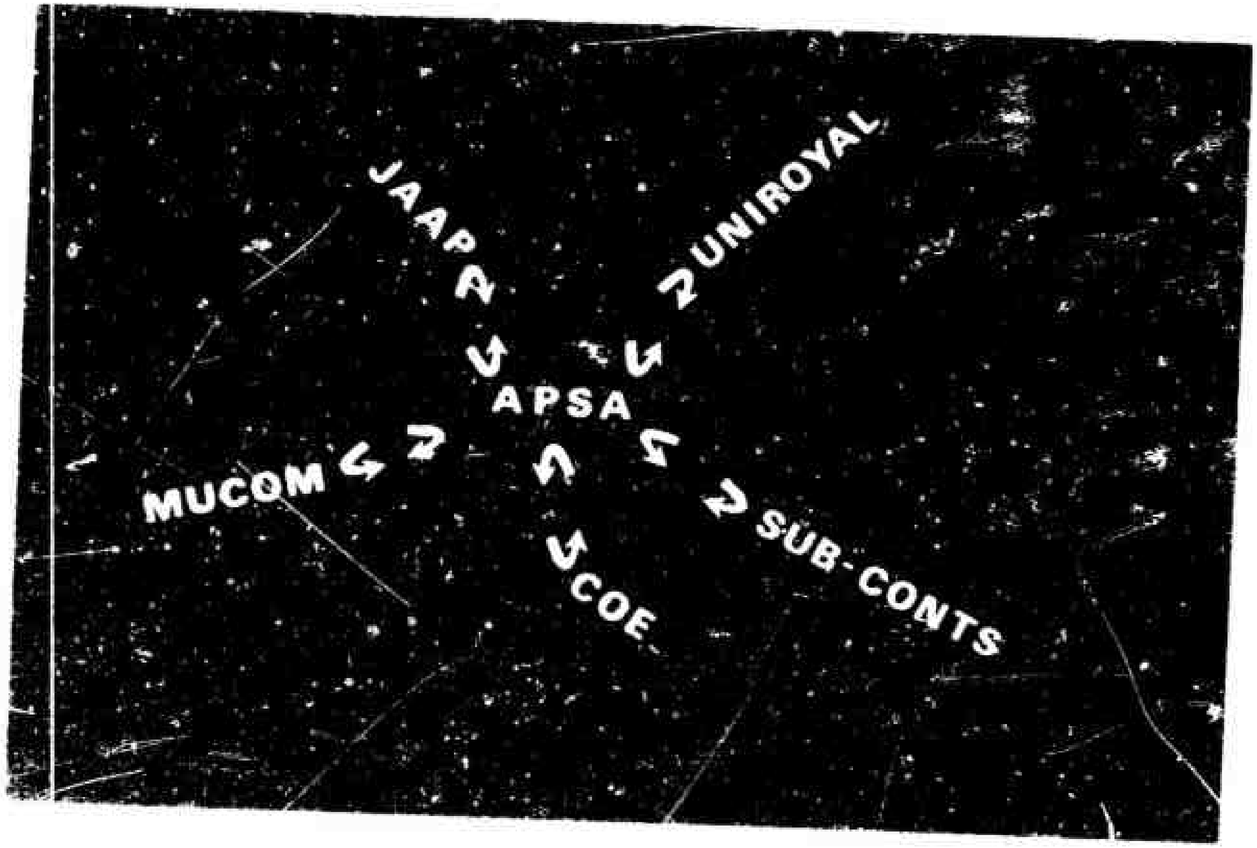
AMCR 385-100 AMC SAFETY MANUAL

AMCR 385-1 SAFETY RESPONSIBILITIES & PROGRAM REQUIREMENTS

MUCOMR 385-23 DECONTAMINATION AND DISPOSAL

APSA PAM 235-1 MAINTENANCE, LAYAWAY & DECONTAMINATION OF FACILITIES

DLSC BULLETIN 20 FEB 69, EXPLOSIVE & ACID CONTAMINATED
CONTRACTOR INVENTORY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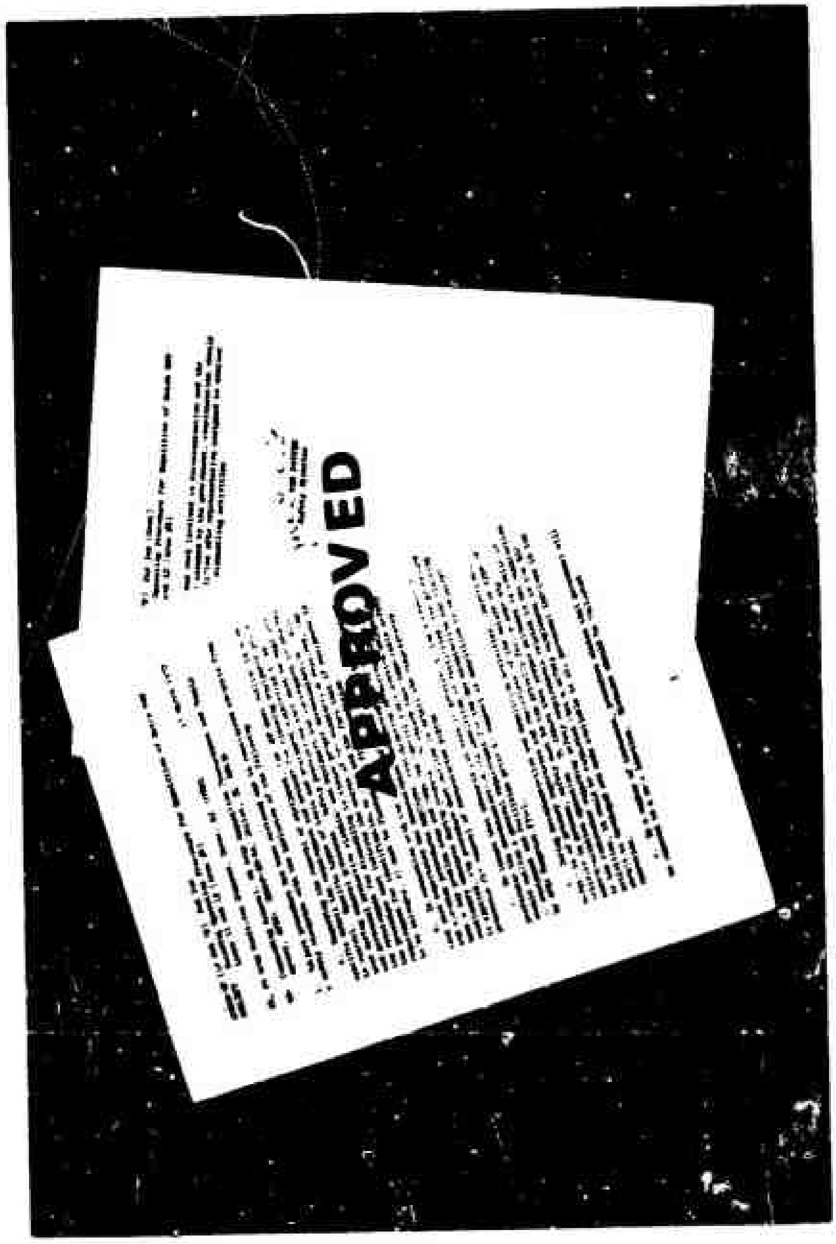
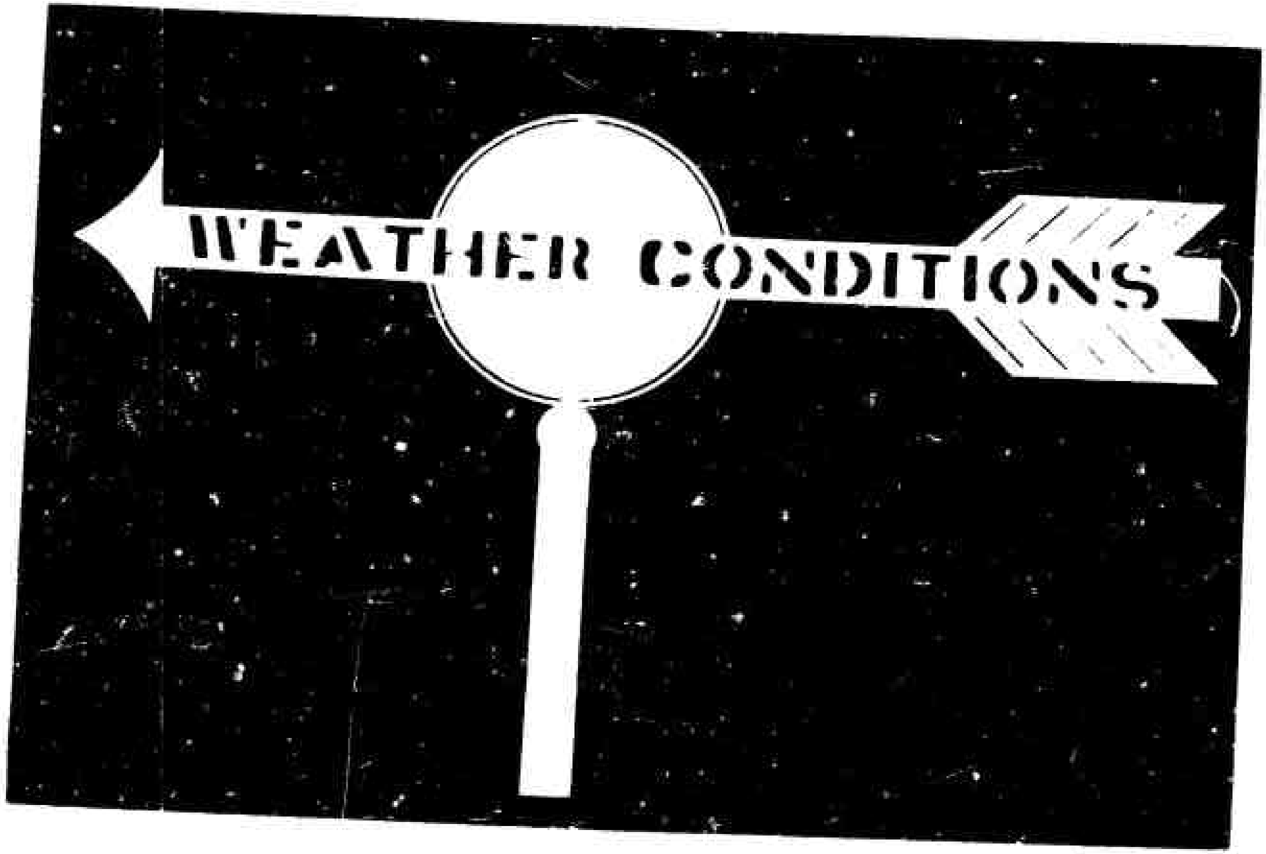


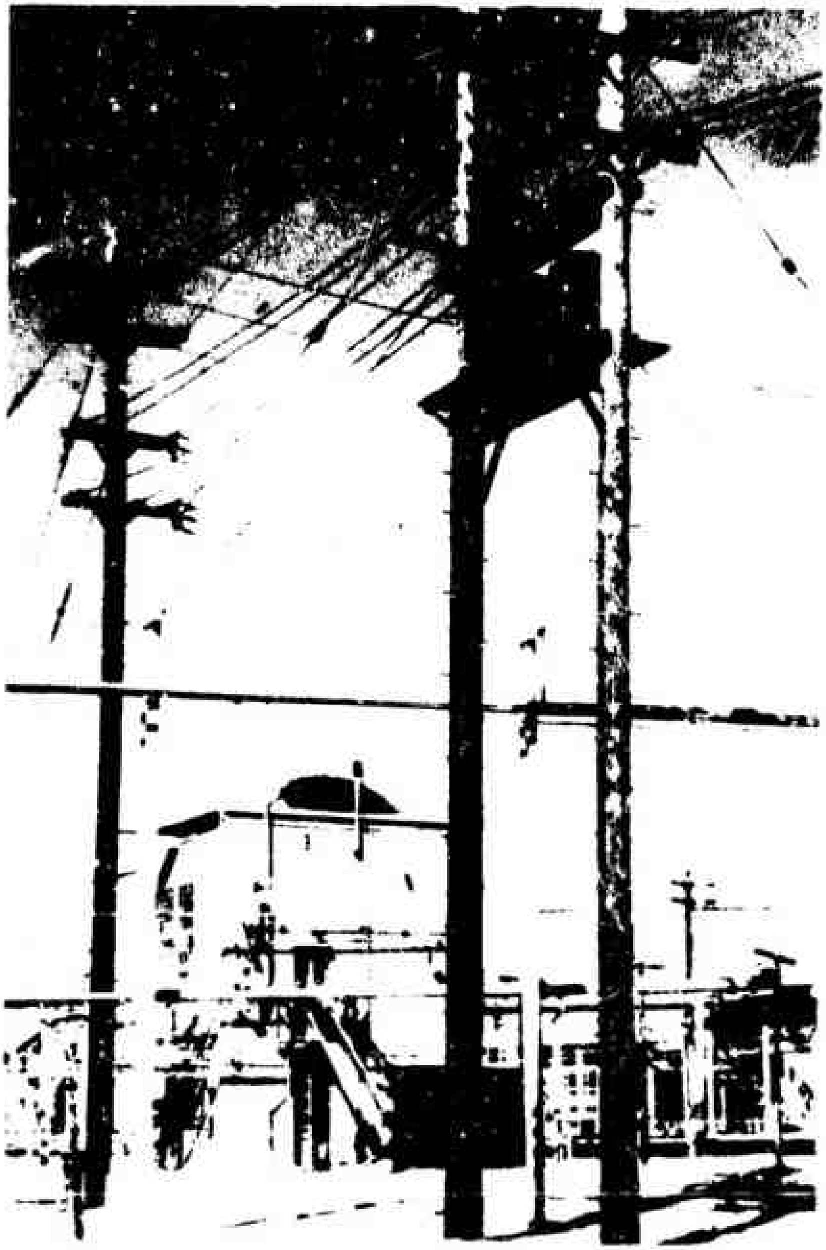
Slide 7

UNKNOWN

HISTORY OF OPERATION

1940 ? 45


WEATHER CONDITIONS



Slide 12

EXPLOSIVE WASTE INCINERATION

Irving Forsten
Picatinny Arsenal
Dover, N. J.

INTRODUCTION

All manufacturing and loading operations associated with munitions manufacturing, produce varying degrees of explosive and propellant solid waste material. Traditionally the waste material is transmitted for disposal to a pad located in an isolated area of the plant property. When weather conditions are right, the combustible mass is ignited and permitted to burn in the open. Ensuing are clouds of various combinations of orange, black and white smoke. Hardly an environmentally acceptable sight. Pollutants in the form of particulate matter and noxious gases such as NO_x are freely emitted into the atmosphere. Obviously the above described process results in air pollution and water pollution from residue solubility, is uncontrolled in operation and is inefficient as a combustion process. Of the various techniques being considered for disposal of the solid wastes described, controlled incineration affords promise as a near term feasible approach to meet the oncoming pollution abatement standards under which "Government Owned Contractor Operated" plants will function.

To address the solution required in developing an explosive and propellant waste incineration system, the approach taken was to:

1. Study, select and test the closest to an off-the-shelf incinerator adaptable to combustion of solid explosive and propellant waste materials. This was intended to provide immediate stop-gap support to the program to fill an immediate need. The system thus under pilot development as part of the overall Picatinny Arsenal, Plant Modernization Support effort is being conducted by Radford Army Ammunition Plant at Radford, Virginia.

2. To develop design criteria in support of all plant requirements using a pilot unit at Picatinny Arsenal and drawing upon applicable technology of a fluidized bed combustion process being developed under contract to Esso Research Corporation, Linden, New Jersey.

The aforementioned comments are summarized by Figure 1.

DISCUSSION

The Radford Army Ammunition Plant Pilot of an explosive waste incineration system is depicted by Figure 2. Here a slurry (usually 10% by weight TNT in water) is fed to a rotary combustor that is fired by fuel oil, which serves to evaporate the water and ignite the combustible ingredients. Combustion occurs in an oxygen rich atmosphere in the first (rotary) combustor. The after-burner serves to burn off unburned particles and hydrocarbons. The water injected into the precooler serves to reduce the temperature leaving the afterburner from approximately 1700°F to 250°F so as to provide acceptable entry conditions into the scrubber. The wet scrubber removes particulate matter and NO_x gases to provide environmentally acceptable (based upon Army Procurement Supply Agency Guidelines) emission as follows:

Particulate matter	< 0.2 grains/st'd cu. ft. corrected to 12 percent CO_2
NO_x	< 200 ppm (ppm = parts per million)

The rotary kiln incinerator has been operated successfully with both propellants and explosives. Approximately 75 hours of operating time has been accrued on the system. Propellant runs have taken place with durations of from 20 minutes to 4 hours at slurry levels by weight of solids of 5 - 25%. The latter figure is equivalent to 400 lbs. per hour of solids consumed. Propellants burned include single, double, and triple base types. Initial successes have been achieved in incineration of explosives with TNT at a slurry level up to 10% equivalent to approximately 160 lbs. per hour of TNT consumed.

The pilot incinerator being developed at Picatinny Arsenal studies combustion characteristics under vertically induced draft action. As seen by Figure 3 the upper level contains oil burning equipment, under induced air action followed by a feed of explosive waste in a water slurry which is transmitted into the combustion chamber at approximately the mid level. Safety features include explosive blow-out doors and automated shut-down controls. The

discharge passes through a cyclone dust collector for removal of particulate or ash residues prior to transmittal to a pollution control system and then is released to a 125 foot stack. The physical dimensions of this incinerator, which are not optimized for this application and quantities of material flow, is 10 feet in diameter by 30 feet high.

As is the case of the work being conducted at Radford, stack emission measurements are being made to establish the gas pollution control measures required.

A total of 6 hours of operating time has been accrued on the system with durations of approximately a minute to a half-hour consuming various explosives such as TNT, Comp B, RDX and HMX. In all cases combustion was achieved in a safe operational manner.

TNT and Comp B were transmitted in slurries of 5 to 12 3/4 % by weight of solids (250 lbs. per hour). The RDX and HMX runs were conducted at slurries of 5% - 21% (410 lbs. per hour of solid material).

Figure 4 shows the profile achieved through the combustion zone of the incinerator under start up conditions. Ability to achieve steady state operations in less than one minute of transfer time of the slurry mix is considered highly significant. It should be noted that the incinerator is fired up under oil burning conditions and the temperature stabilized, after a period of several hours, prior to injection of explosive slurries.

Figure 5 describes another combustion system approach to an explosive and propellant waste incinerator. It utilizes fundamentally the fluidized bed mechanism which contains sintered alumina (Al_2O_3) as the flotation media, thereby providing rapid agitation and uniform heat transfer throughout the combustion zone. The bed is floated by a mixture of combustion air and propane which passes through a distribution plate and floats the bed. A slurried mix of TNT is transmitted slightly down stream of the distribution plate.

The column size is 6 inches in diameter by 9 feet tall. The slurry mixing tank and discharge sampling points may be seen on Figure 5. Thus far the fluidized bed lab scale model has been run for a total of 31 hours with run durations of as much as 8 hours at slurry feed rates of 5 to 10% (equivalent to 0.5 lb. per hour to 1.3 lbs. per hour of TNT transmitted).

Preliminary data acquired in the fluidized bed combustor may be seen on Figure 6. For a total feed rate (water plus TNT) of 13 lbs. per hour, consisting of 10% TNT by weight in the slurry, data in parts per million NO, NO_x, CO, HC and O_2 are shown. The one stage combustion data is generated when all the combustion air and propane is injected at the entry point to the distribution plate (Figure 5). When the valve is opened and the combustion air is apportioned above and below the distribution plate, the data shown by figure 6 as two stage is indicated. This shows that with the different types of staged combustion operation and using the same total inflow to the system, a significant reduction in NO_x produced can be achieved merely by altering the distribution of combustion air.

CONCLUSIONS

1. It is feasible to incinerate a variety of explosive and propellant waste materials in an ecologically acceptable manner.

2. The technology is available for introducing a particular incinerator design to meet a specific plant need.

FIG I
WASTE EXPLOSIVE & PROPELLANT DISPOSAL

PRESENT METHOD

- OPEN BURNING TECHNIQUE

RESULTS IN

- AIR AND WATER POLLUTION
- UNCONTROLLED OPERATION
- INEFFICIENT OPERATION

PROPOSED TECHNOLOGY

- CONTROLLED INCINERATION

PICATINNY ARSENAL PROGRAM

- TO DEVELOP DESIGN CRITERIA FOR ALL GOCO PLANTS USING VERTICAL, INDUCED DRAFT INCINERATOR, ADVANCED FLUIDIZED BED COMBUSTOR AND SUPPORT EQUIPMENT (@ PICATINNY ARSENAL)
- STUDY, SELECT AND TEST BEST CURRENT OFF-THE-SHELF INCINERATOR TO MEET IMMEDIATE NEEDS (@ RADFORD AAP)

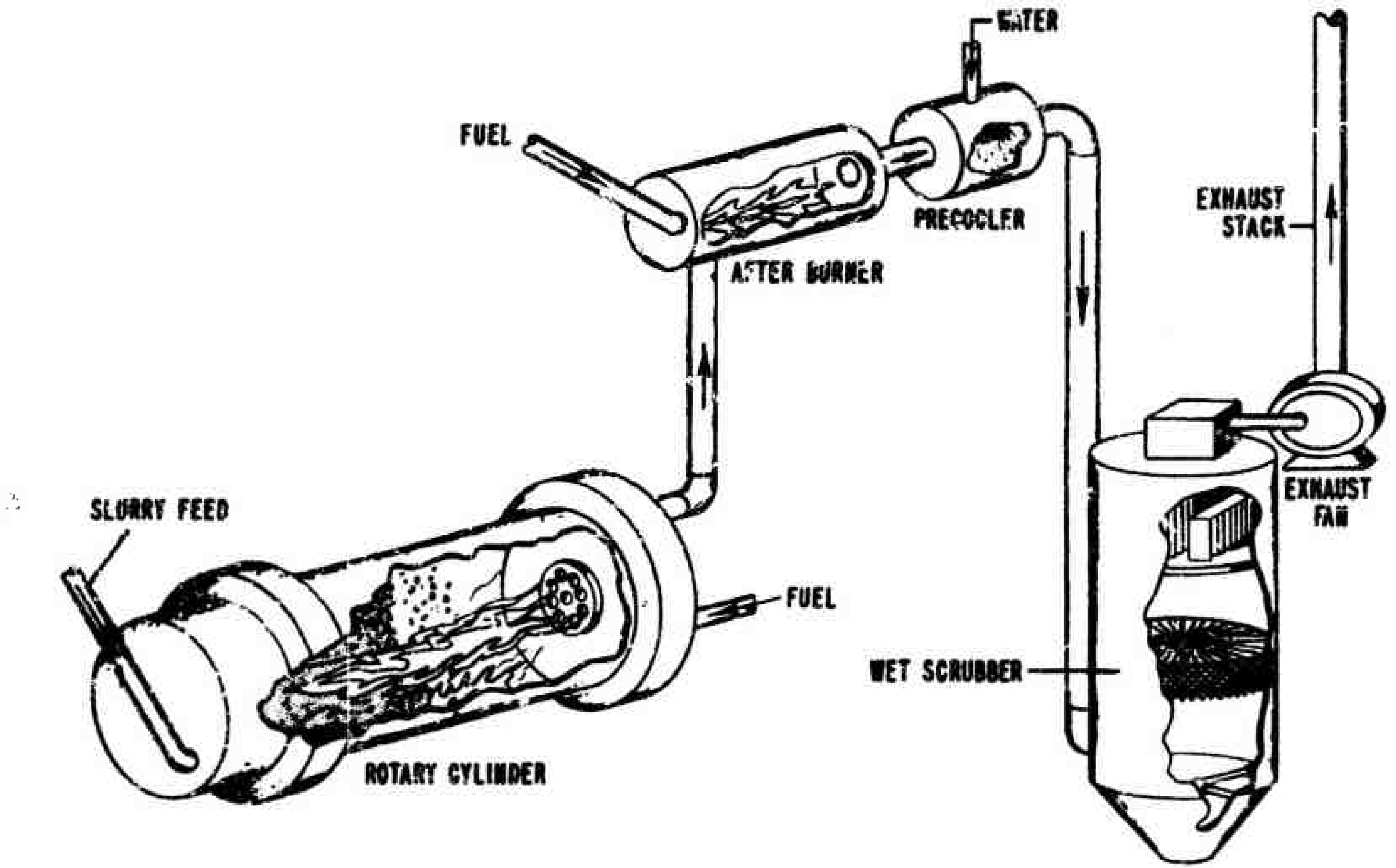


FIG 2 ROTARY KILN INCINERATOR SYSTEM

FIG 3 PICATINNY ARSENAL INCINERATOR FOR EXPLOSIVE & PROPELLANT WASTES

1. OIL BURNER EQUIPMENT
2. EXPLOSIVE WASTE SLURRY LINE
3. INDUCED DRAFT FAN
4. FLUE TO STACK
5. EXPLOSIVE BLOW OUT DOOR
6. HOPPER
7. CYCLONE DUST COLLECTOR

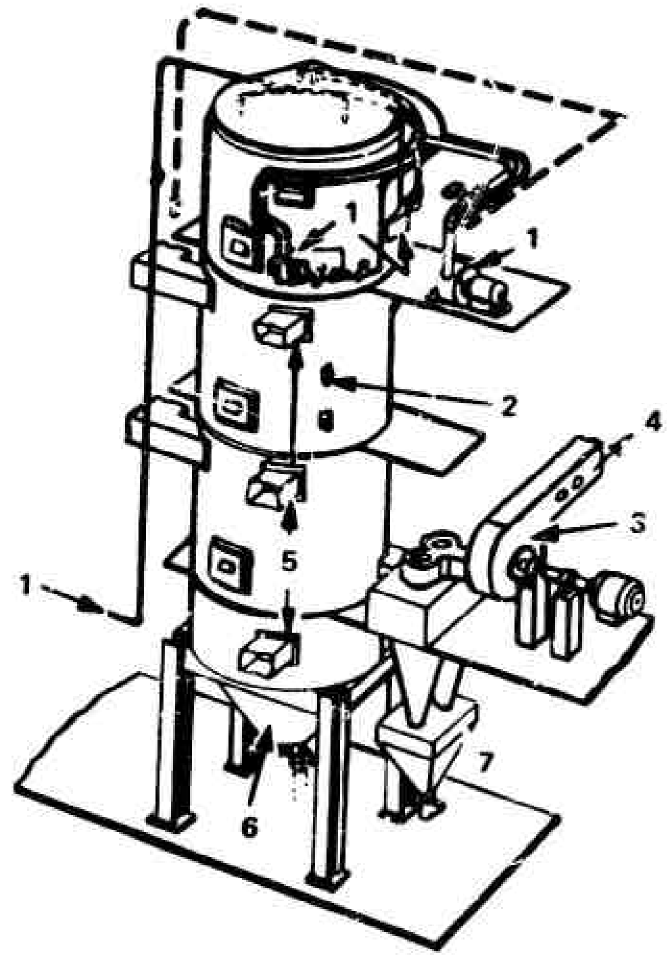
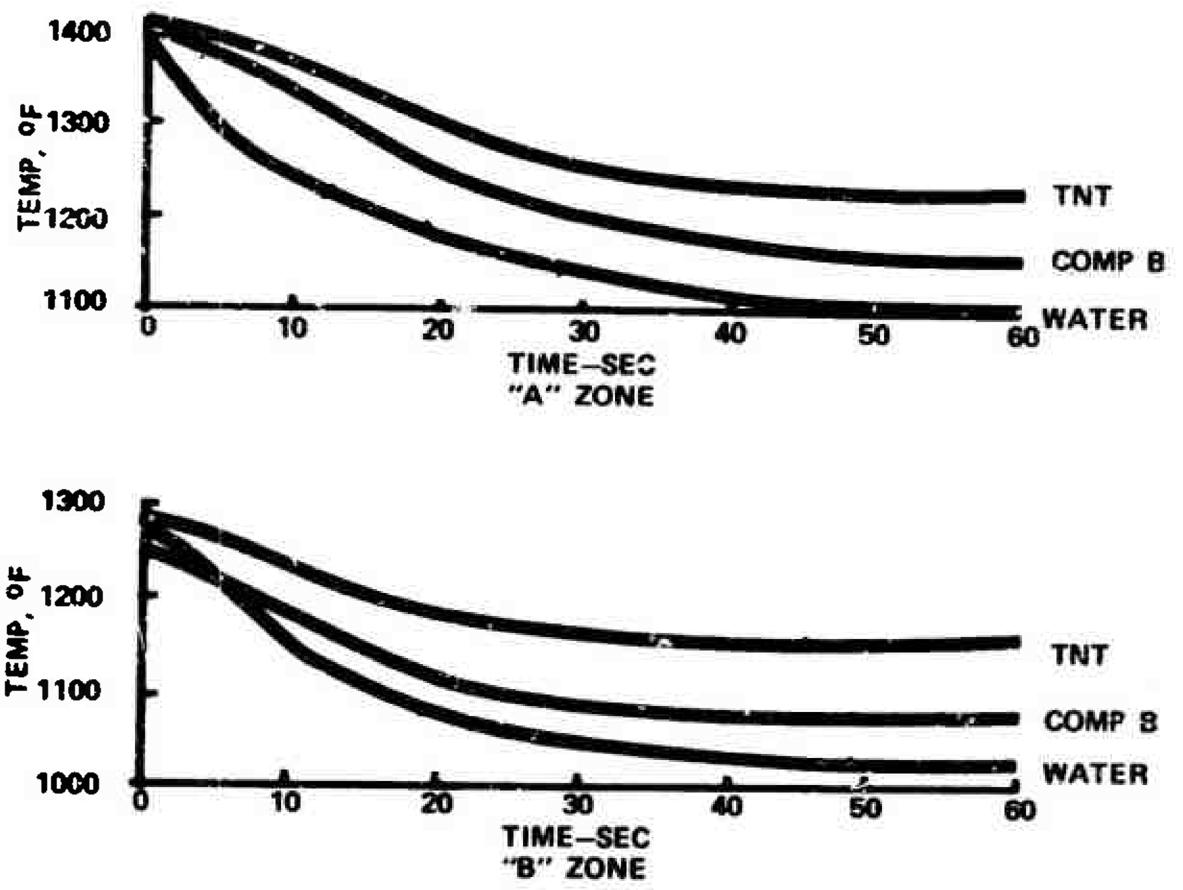


FIG 4

COMBUSTION ZONE TEMPERATURE PROFILE

(12.75% EXPL/WATER SLURRY)



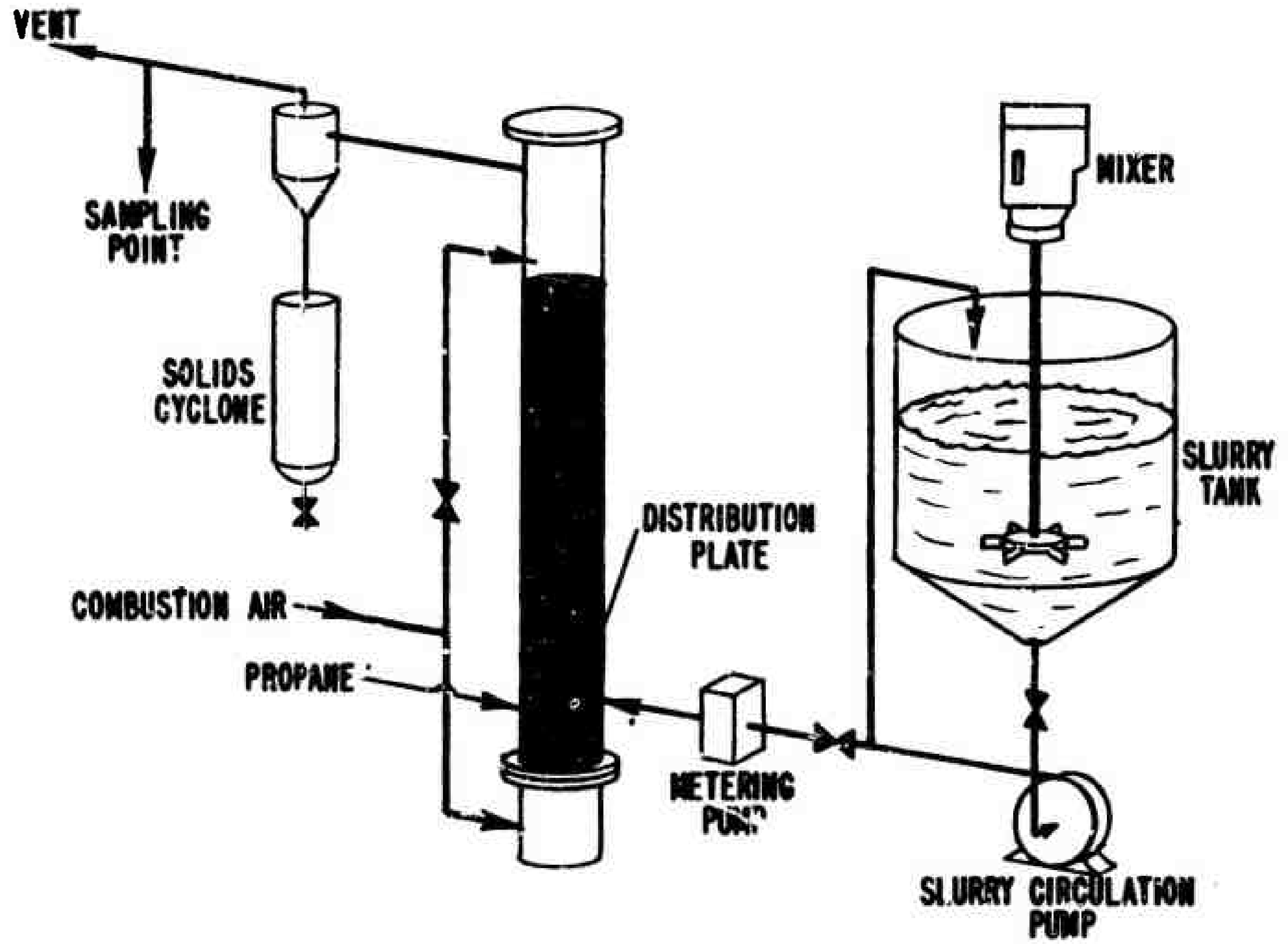


FIG 5 LAB SCALE FLUIDIZED BED COMBUSTOR

TEMPERATURE: 1700–1850° F

DURATION: 5 hrs

VELOCITY–SUPERFICIAL: 4.8–5.5 ft/sec

FEED RATE: 13 lb/hr 10% TNT/WATER SLURRY

	1 STAGE	2 STAGE
NO	1650 ppm	800 ppm
NO_x	1750 ppm	840 ppm
CO	640 ppm	650 ppm
HC	290 ppm	350 ppm
O_2	5.5 %	4.0 %

FIG 6 FLUIDIZED BED COMBUSTION EMISSION DATA

INTERNAL EXPLOSIONS IN VENTED AND UNVENTED CHAMBERS

by

Robert G. S. Sewell
Naval Weapons Center
China Lake, California

and

Gilbert F. Kinney
James E. Sinclair
Naval Postgraduate School
Monterey, California

INTRODUCTION

An internal explosion is one occurring in a confined volume of air as in a tank, coal mine, motor boat, grain elevator or ship compartment. Its damage mechanisms are those of direct blast, if any, but augmented by hydrostatic pressure rise generated in confined air as this is warmed and as gaseous products are released in the explosion. These augmenting effects of warming and gas generation can make an internal explosion appreciably more damaging than an equivalent one in the unconfined atmosphere.

TYPICAL PRESSURE-TIME HISTORIES

The hydrostatic pressure rise in an internal explosion persists for an appreciable time, but also varies with time and so shows a fairly complicated pressure-time history that can be divided arbitrarily into four phases. First is the initial blast, if any. Next, the warming effect of energy release causes a hydrostatic pressure rise, and this may be enhanced by gases generated in the explosion. After the pressure rise there is a short period of sustained hydrostatic pressure as the transient effects of chemical dissociation in the flame front go away. The final phase is pressure decay as confined hot gases are cooled and as material is lost by venting. A schematic for the early portion of such a pressure-time history is shown in Fig. 1. A subsequent figure to a coarser scale shows more of the final pressure decay phase for two different explosions.

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TRANSIENT BLAST PHASE

The initial blast generated in a confined volume by a centrally located charge of conventional explosive is quite similar to the blast it would generate in the unconfined atmosphere. A difference perhaps is that in an internal explosion the reflected rather than the side-on overpressure is of concern. Nevertheless, the scaling laws for explosions still apply. There are complications, however, with off-center charges which may puncture a bulkhead, and with multiple internal reflection effects, particularly at corners.

This transient blast phase lasts only until pressure uniformity is established in the confining volume. Pressure uniformity occurs quickly, usually within blast duration were it unconfined. Such times are so short that it is difficult to measure such transients on instruments selected for study of the overall internal explosion. Furthermore, such transients do not even exist in internal explosions with nondetonating fuel-air mixtures. Thus, the contribution of the initial transient blast effect to the overall pressure-time integral (impulse) ordinarily is not significant and often may be omitted from consideration.

HYDROSTATIC PRESSURE RISE

The hydrostatic pressure rise phase in an internal explosion begins as the initial transient blast dies away and pressure uniformity in the confining volume is established. This pressure rise results from energy release in the explosion process and from generation of additional gases and may be a slower process. Its important aspects are the time required for the rise and the peak pressure that is attained.

Pressure Rise Times

The time required for the hydrostatic pressure rise to reach its maximum value depends on many factors. Among these are the type of combustible material involved, the amount of oxygen available for the process, system pressure and temperature, ignition conditions, and degree of turbulence in the flame front. It does appear that some generalizations about rise times can be made. One is that the rise time in a particular system is about proportional to the volume of that system, and also about proportional to the amount of oxygen consumed in

the combustion aspect of the explosion process. This rise time also is approximately inversely proportional to the surface area of the flame front, which in turn appears to be about proportional to the internal surface of the confining volume. Combining these proportionalities and introducing a constant of proportionality b, the pressure rise time t_r can be expressed as

$$t_r = b\ f\ V/S \tag{1}$$

where V is the confining volume and S its internal surface area. Here, the factor f is the fraction of atmospheric oxygen initially present that is consumed in the combustion.

The fraction of initial atmospheric oxygen consumed in the explosion depends on the amount of material causing the explosion and on its type. For fuel-air explosions and for those with an oxygen-deficient explosive such as TNT, this involves the chemical stoichiometry of the reaction, but has a maximum value of unity. For oxygen-rich explosives such as nitroglycerin, no atmospheric oxygen is consumed and the factor f has the value zero indicating a nearly instantaneous pressure-rise time.

The rise time coefficient, b, of the above equation has a numerical value of about 120 milliseconds per meter for internal explosions of turbulent methane-air and propane-air mixtures, for nebulized fuel oil-air mixtures, and also for internal explosions with detonating explosives such as TNT. Its numerical value is somewhat greater, about 600 milliseconds per meter for dust explosions and for nonturbulent fuel-air explosions, indicating a longer rise time for these slower explosion processes. Such approximate values should be used only in absence of better information.

Peak Hydrostatic Pressures

The peak hydrostatic pressure in an internal explosion is reached as gases in the confining volume reach their maximum or peak temperature. By the ideal gas law

$$P_m/P_o = (T_m/T_o)(n_m/n_o) \tag{2}$$

where pressures P and temperatures T are on absolute scales, n represents the number of moles of gases present, and subscripts m and o identify maximum and initial values, respectively. This relation pertains only to adiabatic constant

volume conditions. Such conditions are met here because the pressure rise times, though longer than blast durations, are so short that there is negligible heat transfer and (relatively slow) gas leakage effects.

For the special but not unusual situation that the relative number of moles of gases generated in an explosion is not great, the above equation can be expressed in terms of increments as

$$\Delta P/P_o = \Delta T/T_o \tag{3}$$

These equations indicate a strong dependence of hydrostatic pressure rise in an internal explosion on the temperature generated in the confined volume. Two rather different situations exist here and are best described separately.

Peak Temperature Less Than Fireball Temperature

For an internal explosion with a relatively small amount of explosive, the average temperature generated in the confined gases is less than the flame temperature for the fireball. In this situation, gas temperature rise can be related directly to the total energy released in both detonation and combustion. For a total energy release Q into n moles of gases, the relation is $Q = n\,\overline{C}_v\Delta T$, where $\overline{C}_v$ is the mean molar specific heat at constant volume. This is related to the more customary specific heat at constant pressure by the ratio k, as $k = C_p/C_v$, and for ideal gases by their difference, as $C_p - C_v = R$, the molar gas law constant. The number of moles of gases confined in volume V is given by the ideal gas law as $n = PV/RT$, and these various relations can be combined with Eq. (3) to give

$$\Delta P = Q(k-1)/V \tag{4}$$

for the pressure rise resulting from the warming process. This equation is written for coherent units such as SI units. In SI units pressures are in newtons per square meter, energy in joules, and volume in cubic meters. For the more suitable metric pressure unit of the bar, divide by the conversion factor 10^5.

For those situations where an appreciable amount of gas is formed in the explosion process, the hydrostatic pressure rise of the above equation may be augmented somewhat. This augmentation may be computed as $\Delta P/P = \Delta n/n$, where Δn is the net increase in number of moles of gases. This pressure item is often

minor and if so, it may not be needed in the calculations. The above equations pertain directly to situations where average temperature of confined gas is less than flame temperature of a combustion fireball. With condensed explosives that are oxygen-rich or oxygen-balanced, there is no afterburn or combustion effect; here the combustion flame temperature limitation does not apply. In such cases the above equations for hydrostatic pressure rise are applicable over a much wider range. Also, for condensed explosives that are oxygen-deficient, the total energy release is that of an initial detonation plus a subsequent combustion. Here the flame temperature limitation does not apply directly, but the energy release item must take into account the two different modes involved.

The mean specific heat ratio k of the above equation is a somewhat troublesome item, for it must pertain to the precise temperature range involved in a particular explosion. Its value also depends on the nature and composition of the product gases. Ordinarily, a chief component of these gases is nitrogen, and other components have only minor influence. For practical purposes, it becomes possible to take this ratio as a function of temperature only. A representative value for this mean specific heat ratio is about 1.25. This corresponds to a mean specific heat at constant volume, $\bar{C}_v$ of 33.3 joules per mole degree (7.9 calories), and at constant pressure of 41.6 joules per mole degree (9.9 calories).

Flame Temperature Limitations

The limiting hydrostatic pressure rise obtainable in an ordinary internal explosion is met when all the confined gas is brought up to the flame temperature of the explosion. For the internal explosion of a fuel-like material, this situation corresponds to complete utilization of the initial oxygen content.

The flame temperature limit in a combustion process is set by the energy release and the effects of chemical dissociation. These dissociation effects become important at temperatures above about 2200°K. They act as an energy sink so that additional energy release no longer serves to raise the temperature. In principle, all flame temperatures can readily be determined experimentally and theoretically. However, few such data are available for constant volume conditions. The meager ones available indicate temperatures in the order of 2500 to 2600°K (2200 to 2300°C) values which are appreciably (perhaps 300 degrees)

greater than those for constant pressures. These temperatures indicate a corresponding maximum hydrostatic pressure rise in the internal explosion of, say, a methane-air mixture of something in the order of 8 to 10 bars (115 to 150 psi).

As pointed out previously, these flame temperature limitations can actually be evaded in the situations of detonating explosives. A quantity of explosive greater than that which utilizes all the confined oxygen in a subsequent afterburn can supply additional energy release by the detonation process. This can give a hydrostatic pressure rise correspondingly greater than the above indicated limit of about 10 bars.

SUSTAINED PRESSURE PHASE

After culmination of the hydrostatic pressure rise, there follows a short period of sustained pressure. During this phase, two opposing effects occur: (1) the cooling effect of heat transfer to confining walls, and (2) that of energy release as the constituents formed by chemical dissociation in the flame front recombine to form stable molecules. The result is a sort of rounding top to the pressure-time curve. Analysis of this phase has not been rewarding; however, it does appear that its duration is about that of the pressure rise phase.

PRESSURE DECAY

A relatively long period of pressure decay follows the hydrostatic pressure rise created by energy release in an internal explosion. During this period the pressure reverts to ambient. There are two mechanisms for this decay; one is thermal in nature as heat is transferred from hot products to cool confining walls, and the other is mechanical in nature as pressurized gases are forcibly ejected through vents in the container. Figure 2 shows typical pressure decay curves for internal explosions of PETN, an explosive in approximately oxygen balance so that neither the initial blast nor the pressure rise phase appear on these coordinates. The upper curve depicts the effect of heat transfer only, and the lower curve shows the combined effect of heat transfer and appreciable venting.

THERMAL EFFECTS

Energy transfer by heat flow from hot confined gases to cool confining walls produces a temperature drop with corresponding pressure drop. The two

mechanisms for this heat transfer are by radiation, and by combined conduction and convection.

Heat transfer by radiation is described by the Stefan-Boltzmann relation and is proportional to the difference in the fourth powers of the temperatures. The basic relation adapted to practical situations can be written for a heat flow in watts as

$$\dot{q}_R = dQ_R/dt = 5.670\ f_a f_e A\ [(T/100)^4 - (T_o/100)^4] \tag{5}$$

Here, A represents a pertinent surface area in square meters and f_a is a factor to account for system geometry. This area is conveniently taken as that of the confining walls with an area factor of unity. The factor f_e is a net emissivity factor for the system. The solid confining walls show essentially black body behavior with complete absorption and reradiation, giving an individual emissivity of unity. Emitting gases, in general, are less radiant and usually show an emissivity factor of about 0.3 for typical furnace temperatures and dimensions. Preliminary calculations for internal explosions indicate that here the gas emissivity factor is appreciably greater, an effect perhaps to be associated with entrained solids and dust in the turbulent fireball. Thus, the calculations show that heat transfer by radiation is a more important factor in the pressure decay process than perhaps is ordinarily recognized.

Conduction-convection effects at the high temperatures of internal explosions are less than those of radiation. They do occur however and seem to follow a conventional heat transfer relation involving the five-fourths power of the temperature difference. In conventional coefficient form

$$\dot{q}_C = 2.0(T-T_o)^{1/4}\ A\ (T-T_o) \tag{6}$$

where the magnitude coefficient is representative of conventional situations. For internal explosions a somewhat larger value seems to apply; an effect perhaps to be associated with the extreme turbulence and agitation caused by an explosion in a confined space.

To convert the sum of the above two thermal effects into pressure effects, Eq. (4) can be adapted to provide a rate of pressure decay $\dot{P} = dP/dT$ as

$$\dot{P} = (\dot{q}_R + \dot{q}_C)(k-1)/V$$

There is no analytic solution for this differential equation and numerical methods are indicated. Preliminary calculations indicate that the equation provides theoretical results for nonvented explosions that essentially parallel the experimental ones. This is illustrated in Fig. 3 where experimental results are compared with ones computed using conventional heat transfer relations and coefficients. It is felt that adjustment of the coefficients to account for the presumably more severe conditions in an internal explosion can bring about good agreement.

VENTING

Venting is mass discharge of products in a partially confined explosion. This gives a pressure relief both by reducing the amount of gases remaining in the confining volume and by an internal cooling as these gases expand to provide the energy required for the ejection process.

The rate of mass discharge depends on the area of the vent and on the initial pressure, temperature, apparent formula mass, and specific heat of the gases. From compressible fluid flow theory it develops that for the situations important here, the initial pressure is sufficiently great that it always produces discharge at sonic velocity. Hence, ambient downstream pressure has no influence on venting rate. As for the geometry of the venting area, only its total is important, not its configuration or distribution. This vent area can be assumed to have reasonably sharp edges so that the discharge coefficient can be taken as about 0.6. That is, vena contracta effects reduce actual rate of flow to 60% of the ideal isentropic rate.

Energy for ejection of vented gases and the kinetic energy they carry with them are supplied by an internal expansion effect. There is a resultant cooling and consequent pressure drop. Such effects can be characterized by the conventional thermodynamic treatment for semi-flow processes.

Analysis of these two effects of venting, mass discharge and internal cooling is proceeding and preliminary results are encouraging. Like the analysis for thermal effects, the result is a simple differential equation that requires numerical solution. Fortunately, the two equations (one for thermal effects and one for venting) can be combined to somewhat simplify the calculation procedure. Preliminary results of this analysis of venting effects show that they are relatively

slow and cannot have significant influence during the initial blast phase or the pressure rise of an internal explosion, and only moderate influence during the sustained pressure phase. However, they become quite important during the pressure decay phase. This is well illustrated by the experimental data of the lower curve in Fig. 3. The only difference in the two explosions of that figure is the provision of a venting area in one of them. The importance of this can be seen to be quite profound.

CONCLUSION

The pressure-time history for an internal explosion is more complex than one for a corresponding unconfined explosion. For an internal explosion, the pressure-time curve can be arbitrarily divided into four phases: (1) an initial blast, if any, that rather parallels that of an unconfined explosion, (2) a pressure rise phase due to the warming of confined air by an energy release due to either or both a detonation and a combustion, (3) a sustained pressure phase during which dissociation effects in the flame front disappear as stable molecules are formed, and (4) a pressure decay due to the combined effects of cooling by heat transfer and of mass loss by venting. Not all internal explosions show all four phases; thus, an oxygen-rich condensed explosive shows no pressure rise phase, and a fuel-air mixture shows no blast phase.

Analysis indicates that venting exerts appreciable influence only on the pressure decay phase. For an internal explosion where the impulse of a prolonged pressure pulse is a prime damage mechanism, venting effects can provide significant relief. Such a situation may occur in the explosion of fuel vapors in a tank or in a dust explosion in a grain elevator. However, where the major damage mechanism of an internal explosion is the direct blast, as caused by an underwater torpedo or an armor-piercing projectile, venting should have no significant effect.

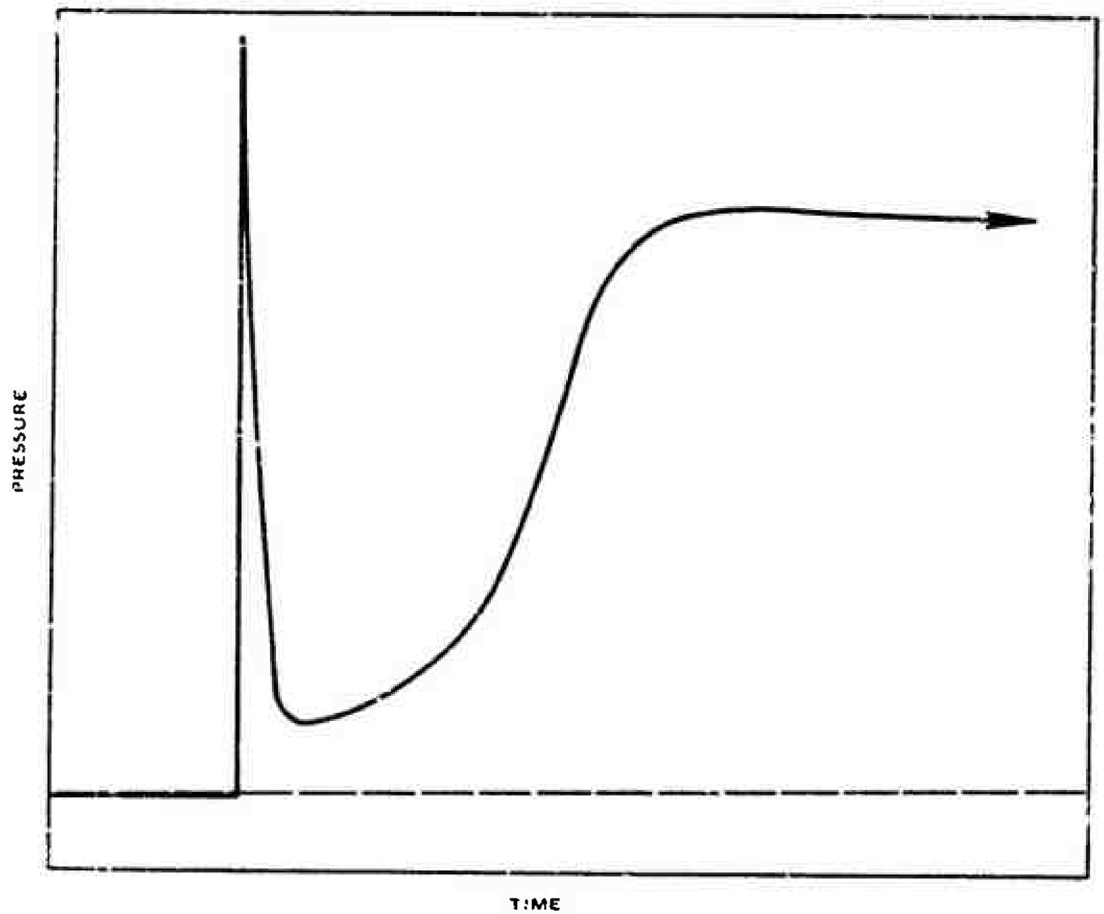

FIG. 1. Schematic of the Early Portion of a Typical Pressure-Time History for an Internal Explosion.

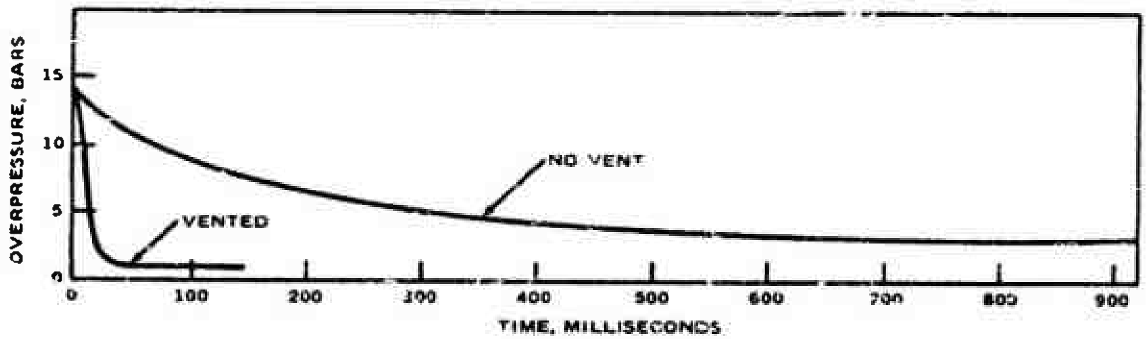

FIG. 2. Pressure Decay in a Vented and in an Unvented Internal Explosion.

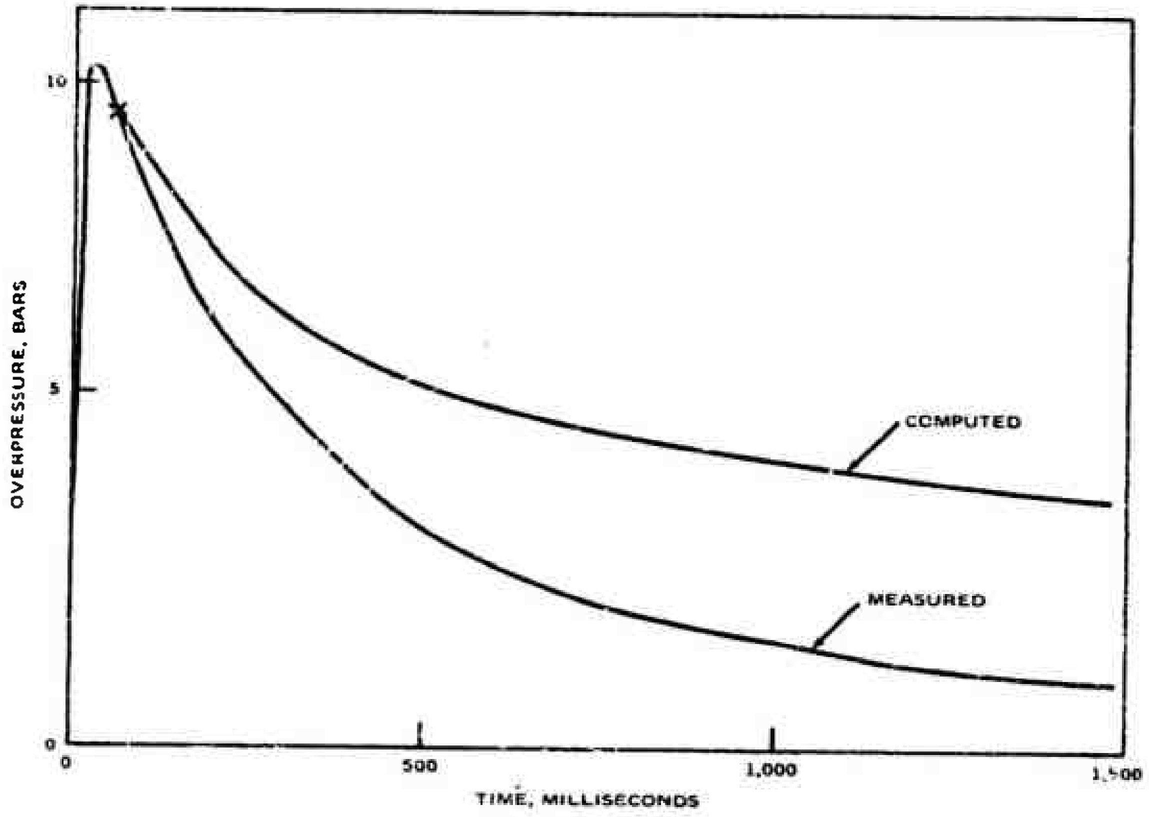

FIG. 3. Measured Decay Curve for an Unvented Chamber, and Curve Computed Using Customary Heat Transfer Coefficients.

A COMPUTERIZED TECHNIQUE FOR BLAST LOADS FROM CONFINED EXPLOSIONS

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ABSTRACT

Facilities for the manufacture, maintenance, modification, inspection, and storage of explosive material are all subject to accidental explosion of a confined type. The design of such explosive containing structures to avoid propagation requires knowledge of the pressure loading that would result from an accidental explosion. In order to improve accessibility to such loading information on a comprehensive and convenient basis, NOL has recently taken state-of-the-art experimental data and explosion theory and has developed a computer program capable of generating characteristic shock wave and quasistatic gas pressure loading parameters in a form readily usable by design engineers. While originally intended for military aircraft designers and vulnerability analysts, the computer program is, with some modification, applicable to any confined explosion problem.

Parameters that may be taken into account in the calculation include (1) weight of explosive, (2) type of explosive (chemical composition), (3) charge geometry, (4) weapon case effects on shock, (5) volume within which

explosion is confined, and (6) pressure, temperature, and oxygen content of the ambient gas within the confining volume. The computer code is also capable of determining the decay rate of the gas pressure due to venting or gross volume changes from wall failure.

INTRODUCTION

One of the current ongoing tasks of the Aerial Target Vulnerability (ATV) Program of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) has been the development of a component damage data bank. An item defined in this bank is the vulnerability of aircraft to internal blast from high explosive projectiles. Under the direction of the Air Force Flight Dynamics Laboratory (AFFDL), the Naval Ordnance Laboratory (NOL) was assigned the task of defining the internal blast loading characteristics.

Specifically, the objective of the NOL program was to develop a computer code for describing blast characteristics associated with the detonation of a high explosive projectile internal to an aircraft structure. Existing state-of-the-art experimental data and explosion theory combined with sound engineering judgment were to provide the primary basis for this program. Construction of the code was to provide easy execution of the program with minimal uncomplicated input, easy adaptability to different computer systems, and concise presentation of the loading results in a form readily usable by aircraft design engineers and vulnerability analysts.

Before proceeding with the code itself a brief examination of the blast phenomena associated with an internal explosion is useful (Ref. (1)).

Pressure-time records shown in Figure 1 reveal the variety of pressure behavior that is typical of high explosive chamber effects. Figure 1a shows a pressure-time record from a high resolution (~50 khz) piezoelectric gage with an expanded time scale. The gage is supported in the chamber space away from the walls. Note that the incident (free air) shock has been completely recorded before the arrival of the first wall reflected shock. If a wall gage were used the first shock recorded would have the largest amplitude. Figure 1b is a reproduction of the same record with a condensed time scale showing numerous wall reflected shocks superimposed on a general pressure rise. Figure 1c is a reproduction of an inductance gage record. The poor high frequency response of this gage (~1 khz) causes the many shock reflections to be filtered out, and results in the recording of only the relatively slow pressure rise. The DC response of this gage makes it effective for long duration pressure measurements such as are encountered in confined blast measurements. Composite smooth pressure-time curves with the pressure axis greatly enlarged and the time axis condensed are shown in Figure 1d. Records similar in appearance to these may be obtained directly by the use of oscillograph recorders (~0.1 khz). Heat loss to the walls results in the slow pressure decay.

GENERAL DESCRIPTION OF CODE

Any size explosion can be accommodated by the code for any ambient altitude condition up to 50,000 ft, and the code includes parameters and chemical compositions of some 28 different explosives including mono, composite, and aluminized varieties. The computer program analytically

treats the internal explosion in terms of two damaging mechanisms--the initial shock wave and the confined-explosion gas pressure. For the shock wave the code generates the incident and normally reflected pressure-time history and impulse for the positive phase duration at a specified distance from the explosion. The code reduces the shock calculation for all cases to the reference data from a free-field, bare, spherical 1-lb TNT explosion at sea level ambient conditions. Variables that affect airblast which are included in the code for establishing an equivalent TNT spherical explosion are:

1. explosive weight
2. type of explosive
3. cylindrical charge geometry
4. case weight
5. ambient pressure and temperature at the location where the explosion occurs.

For an explosion internal to a confining structure, a long-duration quasi-static pressure exists after dissipation of the shock wave. The maximum value of this pressure, termed the confined-explosion gas pressure, is dependent on these parameters:

1. weight of explosive
2. type of explosive (chemical composition)
3. volume of confining structure
4. ambient pressure and temperature of the air initially in the structure.

Because of inadequacies in existing methods of calculating the confined-explosion gas pressure, an improved technique was developed especially for this program that follows the energy generation of the chemical reactions and the changes in gas properties as the confined-explosion gas pressure is developed. In a completely closed structure where heat

losses are neglected, this pressure would remain essentially constant. However, for most real structures, the pressure will decay in time because there will be openings or vent areas through which the confined gases can escape. Also the pressure can change abruptly due to wall failure of the structure compartment that would introduce a new volume of an adjacent compartment into which the gases can expand. The computer program calculates the variation of the confined-explosion gas pressure with time for venting and such volume changes. Vent area and volume changes are controlled by input damage criteria for structure wall failures.

Result printouts for both the shock and venting calculations are in the form of tabulated pressure-time information. At the option of the user, the amount of data printout for either section can be varied to allow for any desired degree of pressure-time data resolution. It is impossible to describe the entire computer program in this paper; therefore, only the technical aspects of the two most important sections are discussed herein, namely the shock and the confined-explosion gas pressure calculational methods. (A complete report on this effort will soon be available (Ref. (2).)

SHOCK CALCULATIONS

EQUIVALENT WEIGHT

Base data for all shock calculations are those from a bare, spherical 1-lb TNT explosion in free-air at sea level conditions. Therefore, it is necessary to relate the detonation of a cased, cylindrical, non-TNT explosive at ambient conditions other than sea level to the base 1-lb spherical TNT explosion. The energy equivalent weight, f_e, that relates airblast performance of a particular explosive to that of TNT is a property given in the list of explosives

programmed in the code. With this factor and a given distance from the explosion, the computer employs conventional Sachs scaling and estimates the magnitude of the peak shock overpressure at sea level. An approximate magnitude of this peak pressure is required by the computer to determine the cylindrical charge equivalent weight, f_s, from the programmed curves given in Figure 2. The low-pressure curve in this figure was derived from experimental data given in reference (3), and the high-pressure curve was derived from work on line charges given in reference (4). To determine the effects on airblast shock of a metal casing surrounding a cylindrical charge, the code utilizes the following equations for the casing equivalent weight, f_c, taken from reference (5).

$$\text{For } 0 \leq M/C \leq 0.53; \quad f_c = 1 - (M/C)^2/(1 + M/C)$$

$$\text{For } 0.53 \leq M/C \quad ; \quad f_c = 0.47 + 0.53/(1 + M/C)$$

where M/C = case weight/charge weight ratio.
A cylindrical, cased, non-TNT explosive charge of weight W can be related to an equivalent bare spherical TNT charge of weight W_{TNT} by the expression

$$W_{TNT} = W \times f_e \times f_s \times f_c$$

The computer takes the equivalent TNT charge weight, W_{TNT}, at the ambient conditions of the actual explosion and the desired distance and finds the scaled distance for a 1-lb TNT spherical explosion at sea level.

PRESSURE-TIME HISTORY

A version of the WUNDY hydrocode, described in reference (6) was used to develop pressure-time-distance information for a 1-lb TNT explosion at sea level. It was found that this information could be accurately represented by the empirical equation

$$\Delta P/\Delta P_1 = (1 - t/t_d)\ e^{-(t/t_d)\left[1 + \frac{(228/R - 0.95)}{(0.5 + t/t_d)}\right]}$$

where ΔP = instantaneous incident overpressure

ΔP_1 = peak incident shock overpressure

t = time measured from shock arrival

t_d = positive phase duration

R = distance from explosion, cm

It is seen from the above relation that only the peak incident shock overpressure, ΔP_1, and the positive phase duration, t_d, are required to generate a pressure-time curve for a given distance, R. These values for a 1-lb TNT explosion were determined by WUNDY and are tabulated in the code as functions of distance. Therefore, for a given scaled distance the computer easily calculates an incident pressure-time curve from the above equation.

The reflection factor, f_R, associated with the normal reflection of the peak incident shock pressure at sea level is determined by the computer from the following equations that are an empirical fit to Brode's reflection curve in reference (7).

For $0 \leq \Delta P_1 \leq 200$ psi ; $f_R = 2\left[\frac{(7)(14.7) + 4\Delta P_1}{(7)(14.7) + \Delta P_1}\right]$

For $200 < \Delta P_1 \leq 10{,}000$ psi ; $f_R = -3.18 + 3.97 \log_{10}(\Delta P_1)$

For $10{,}000 < \Delta P_1$; $f_R = 13$

An approximation of the normally reflected pressure-time curve is determined by multiplying the entire calculated incident pressure curve by the reflection factor, f_R, associated with the peak incident shock ovepressure. Numerical integration of the incident and reflected curves is performed by the computer to determine the incident and reflected impulses. Sachs

scaling is employed to transpose this 1-lb TNT sea level data to the ambient conditions of the actual explosion.

Since it is believed that the normally reflected shock loading provides the most meaningful index for assessing aircraft structural damage from shock loading, it is desirable to compare code predictions for reflected shock wave information with available experimental reflected data. The most complete set of reflected data was found in reference (8) for pentolite explosions at sea level. Figures 3 and 4 give a comparison between code predictions and experimental curves from reference (8) for peak reflected overpressure and reflected impulse. The agreement is considered excellent in light of the facts that (1) the predictions fall within the scatter of data from which the experimental curves were drawn and (2) the experimental data represents relatively close-in measurements where analytical predictions would be expected to be their poorest. Additional confidence in the capability of the code to construct accurate pressure-time curves is provided by Figure 5, a comparison of code results with an actual pressure-time trace taken from reference (8). Again the agreement is excellent.

CONFINED-EXPLOSION GAS PRESSURE

Basically the confined-explosion gas preesure develops when, after a short period of time, the explosion energy has become uniformly distributed throughout an enclosed space. The energy that we speak of includes all of that produced in the full course of the confined explosion--the initial shock energy that gradually dissipates after many reflections as well as the residual energy of the explosion products and the latter afterburning energy of these products reacting with oxygen in the air.

A study of existing methods to accurately predict the confined-explosion gas pressure revealed a limited capability to quantitatively describe the above phenomena. Consequently, an improved technique was developed especially for this program to determine this gas pressure. The starting point of this technique is the so-called energy equation of state, $E = PV/(\gamma - 1)$, that describes in basic physical terms the governing variables; where V is the volume of the chamber space and E is the internal energy, P, the pressure, and $\gamma = c_p/c_v$--the ratio of specific heats--of the gas in the chamber. This technique deals with the actual potential for afterburning that affects the total energy released by the explosion and the variation of γ with existing temperature conditions of the various gases.

As input information the code is given the ambient pressure, P_a, and temperature, T_a, of the air contained in the structure volume, V_o. Also the type and quantity of explosive are given. (Chemical composition of the specified explosive is selected by the computer from the programmed explosive properties table.) The program follows a predetermined chemical reaction sequence and determines the quantities of the combustion products, H_2O, AL_2O_3, CO, CO_2, O_2, and N_2, that exist in the volume after the explosion. From these quantities of combustion products and their respective heats of formation, the code calculates the total amount of energy, Q, that is released. In this manner the computer can predict gas products and energy releases that correspond to any degree of oxygen present initially in the explosive compound and the surrounding air.

In the computational model it is assumed that first the mixture of combustion products which occupy the structure volume exists at the initial ambient pressure and temperature of the air, P_a and T_a. The energy released by the chemical

reaction is then added to the product gases governed by a constant volume process. However, this is done in small temperature steps because the specific heat at constant volume varies with temperature. Empirical relations that express the specific heats for the various product gas components as functions of temperature are programmed in the code. The computer adds heat to the gases in steps that continually adjust the specific heats with temperature until all of the energy, Q, released in the reaction is used and the final gas temperature is determined. With the amount of gas in the structure volume known along with the final temperature, the computer then utilizes the perfect gas law to determine the final confined-explosion gas pressure.

The calculational method was evaluated for a series of explosives over a wide range of charge weights to chamber volume ratios and ambient gas conditions. Fortunately, a large body of experimental data has become available in the past decade for checking the calculations. One set of data by Weibull (Ref. (9)) was the result of a series of studies in four different sized chambers ranging from about 15 to 1000 cubic feet in volume. The purpose of these tests was to provide information for the design of a shock tube nuclear blast simulator that employed high explosive as the driving means.

Figure 6 shows calculated results for TNT. The general agreement with measurements reported by Weibull is striking. The dashed lines indicate the results that would be obtained if either heat of combustion or heat of detonation values were used over the entire range with a fixed $\gamma = 1.4$ for standard temperature conditions. For the real case as W/V increases the pressure increase is less than proportional because of the change in specific heat of the gases as temperatures rise. The inflection that is clearly apparent

occurs when the oxygen in the ambient air is no longer adequate to completely burn the explosion products. The transition to heat of detonation results in a lowering of the curve. It then continues up at roughly the previous slope.

In the Weibull paper an empirical curve defined by an exponential equation with two constants was drawn through the data, but the inflection was ignored with the consequence that there is substantial error along most of the length of the curve.

A second set of data published by James and Rowe (Ref. (10) was the result of a series of tests in spherical chambers that were intended to simulate explosion source behavior for studies of seismic decoupling of explosions. The spherical chambers were 6, 1.5 and 0.5 ft in diameter. Figure 7 shows our computations for an RDX/wax charge. There is excellent agreement with the British experimental data. Here again is seen the inflection at the transition from heat of combustion to heat of detonation energies. The experimental data is slightly low relative to the NOL calculations in this region, probably due to the inefficiency in utilization of all the available oxygen in the chamber.

In the James and Rowe paper, some approximate theoretical methods were applied that show the general shape of the curves including the inflection. But only limited success was indicated in quantitatively fitting the experimental data.

In Figure 8 a second set of British data is shown for the ambient gas pressure reduced to less than one-tenth of an atmosphere. There the total available ambient oxygen is reduced by the same fraction as the ambient pressure. Consequently, the inflection occurs at a much lower point on the curve. But again, NOL calculations and British experimental data match very well indeed.

In Figure 9 several other sets of data are included for an oxygen balanced explosive, PETN, a mixture of RDX/TNT and several aluminized mixtures. Once again, at the risk of sounding repetitious, the agreement is good.

These comparisons demonstrate that the computer program can adequately predict the confined-explosion gas pressure for various explosive compounds and various ambient air conditions over an extremely wide range of charge weight to volume ratios (four orders of magnitude).

SAMPLE PROBLEM

To demonstrate the concise, informative, and easy-to-interpret format of the code printout results, the following sample problem was performed with the computer code.

Given an 8 ft^3 aircraft compartment containing air at 14.7 psia and 20°C. A projectile penetrates the compartment forming an opening of 0.00545 ft^2 area. The projectile contains 0.0294 lb of an explosive fill of 74% RDX, 21% AL, and 5% wax. It has a length to diameter ratio of 2.7 and a case weight to charge weight ratio of 4.24. Shock information is desired at 0.667 ft from the explosion. Normal venting of the confined-explosion gas pressure occurs until a time = 0.15 sec after detonation. If the gas pressure exceeds 45 psia at this time, a structural failure occurs introducing an additional 4-ft^3 volume of air at 14.7 psia and 20°C with an additional vent area of 0.00545 ft^2. If after 0.6 sec of venting the gas pressure exceeds 20 psia, a second structure fails introducing yet another additional 4-ft^3 volume of air at 14.7 psia and 20°C with an additional vent area of 0.00545 ft^2.

Figure 10 gives printout results of the shock calculation for this problem. In addition to printout of input data and calculated equivalent weight and scale factors, note the tabular form of the shock pressure-time information. The shock wave arrives at the desired distance of 0.667 ft in 0.0712 msec after detonation with a peak incident overpressure

of 317.6 psi and a normally reflected overpressure of 2144 psi. At 0.1920 msec after detonation or 0.1209 msec after shock arrival, the initial shock pulse has decayed to zero overpressure. Also of note are the various caution statements that may appear when some specific code calculation is made with an approximation not verified by experimental evidence.

Figure 11 gives printout results on the confined-explosion gas pressure venting and subsequent changes due to structural failures. At the beginning of the printout, input information including the failure criteria table is repeated. Under "properties of gases", the printout gives the code results for the confined-explosion gas pressure (45.9 psi overpressure) immediately prior to venting. Under "begin venting of gases", the variation of gas overpressure with time is given along with other properties of the confined gases. The beginning time is zero for this calculation which is set arbitrarily after the dissipation of the shock wave, and the overpressure is maximum at 45.9 psi. We note the adjustments made with compartment failures and continued venting. For example, at t = 0.15 sec the gas overpressure is 36.5 psi which is above 45 psia and the wall fails. A new pressure of 36.75 psia or 22 psi overpressure is calculated for the new volume of 12 ft^3, and venting continues until t = 0.60 sec when another failure occurs. The code readjusts the pressure to accommodate the new volume and venting continues until the overpressure is essentially zero at t = 0.908 sec.

CONCLUSIONS

It is believed that this computer code represents the most complete and accurate tool for predicting blast loading from internal explosions in existence today. Availability of the code for general use with complete detailed documentation is expected early in 1973. Whereas the code was specifically

designed in its present form for small aircraft compartment damage problems, the concepts and procedures are applicable, with modifications, to any system subject to an internal explosion be it aircraft, naval ship, land vehicle, or building structure. It is hoped that by the end of 1973 the modifications contemplated for large explosions within ships will be incorporated into the code.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Air Force Flight Dynamics Laboratory for the sponsorship of this program. Also to fellow workers, T. O. Anderson, D. Lehto, and C. Richmond, the authors acknowledge their essential assistance in the development of this computer program.

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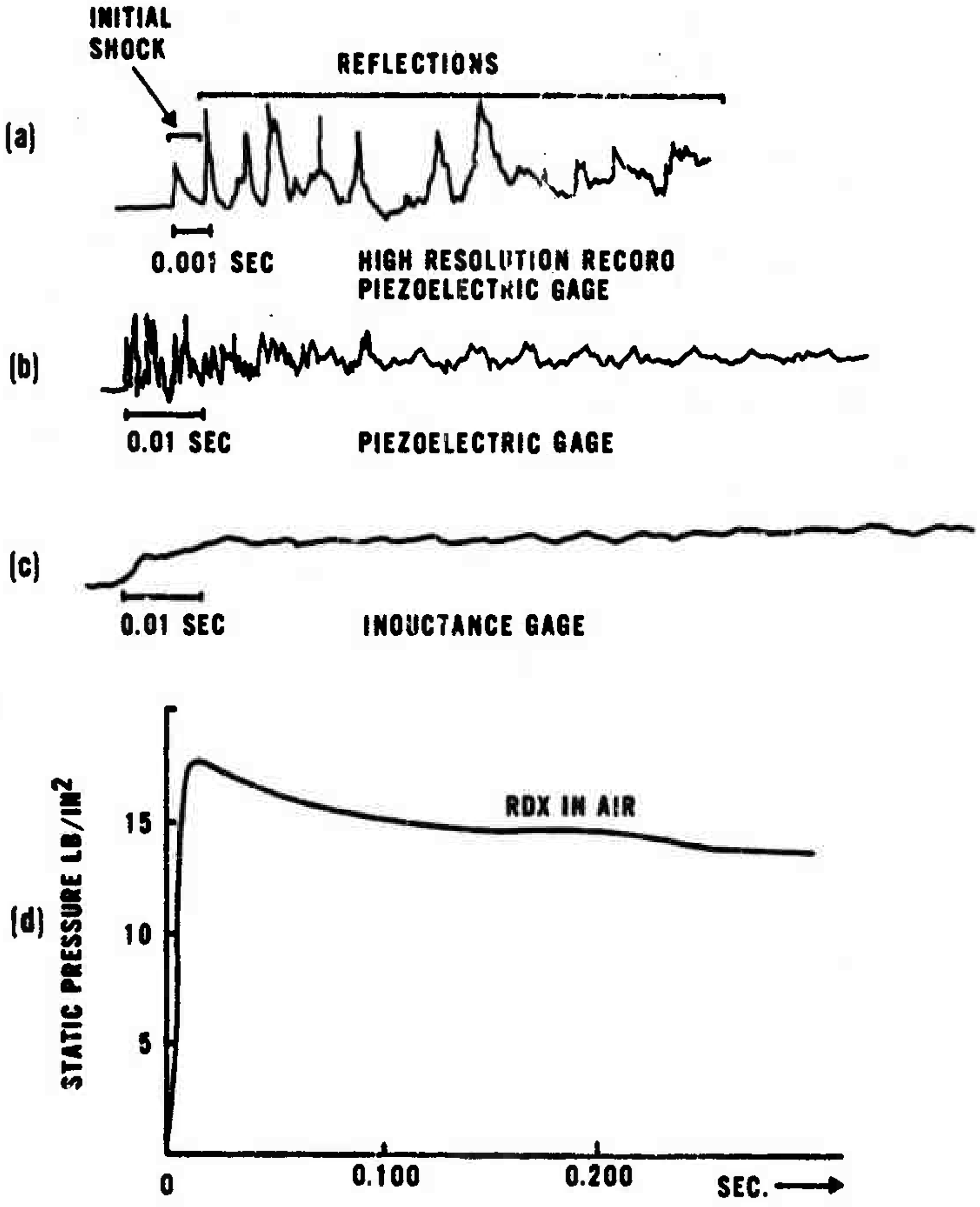

COMPOSITE SMOOTHED PRESSURE -TIME CURVES WITH PRESSURE AXIS ENLARGED AND TIME AXIS COMPRESSED

FIG.1 TYPICAL PRESSURE-TIME RECORDS FOR A CONFINED EXPLOSION

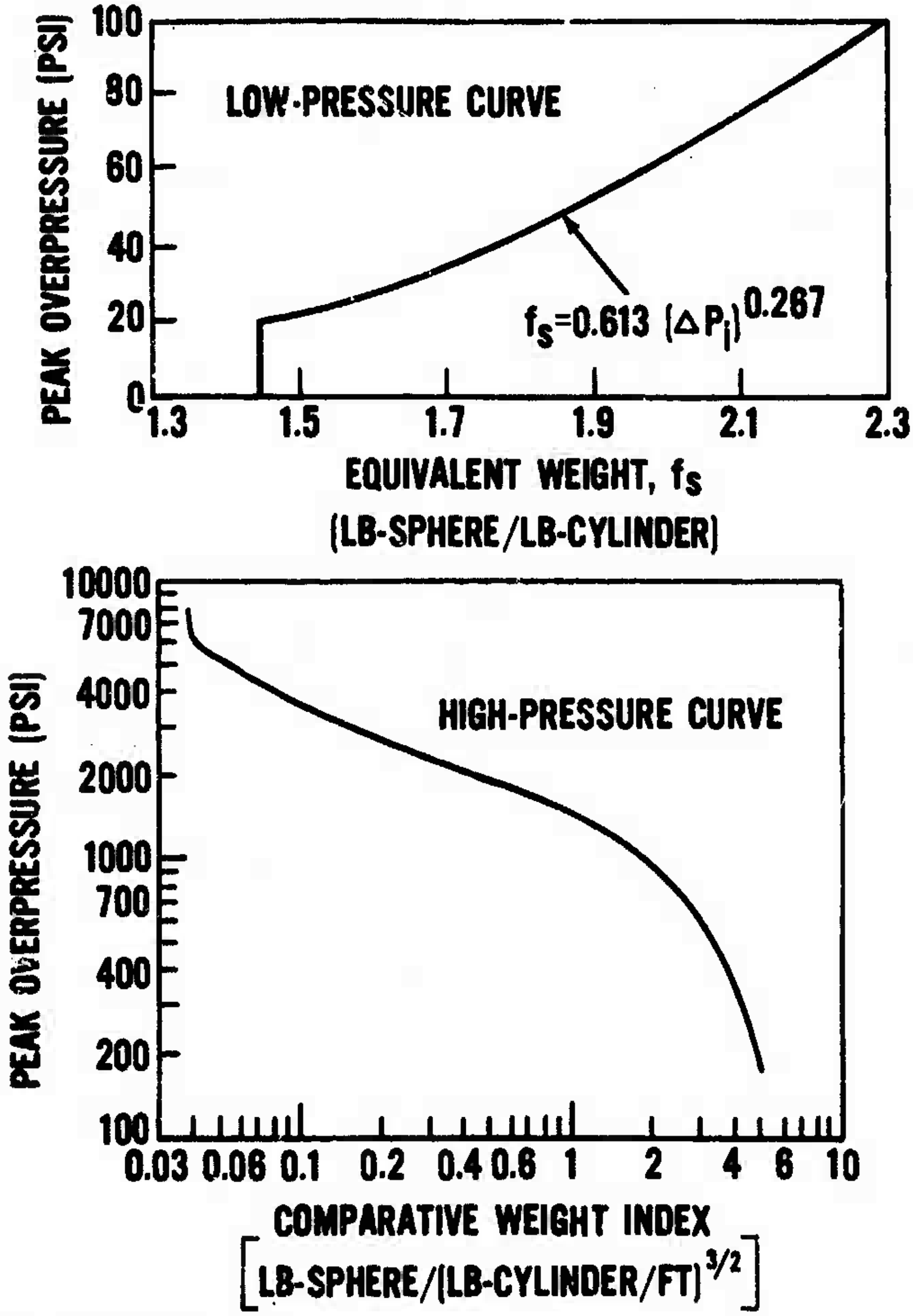

FIG. 2 CYLINDRICAL CHARGE EQUIVALENT WEIGHT

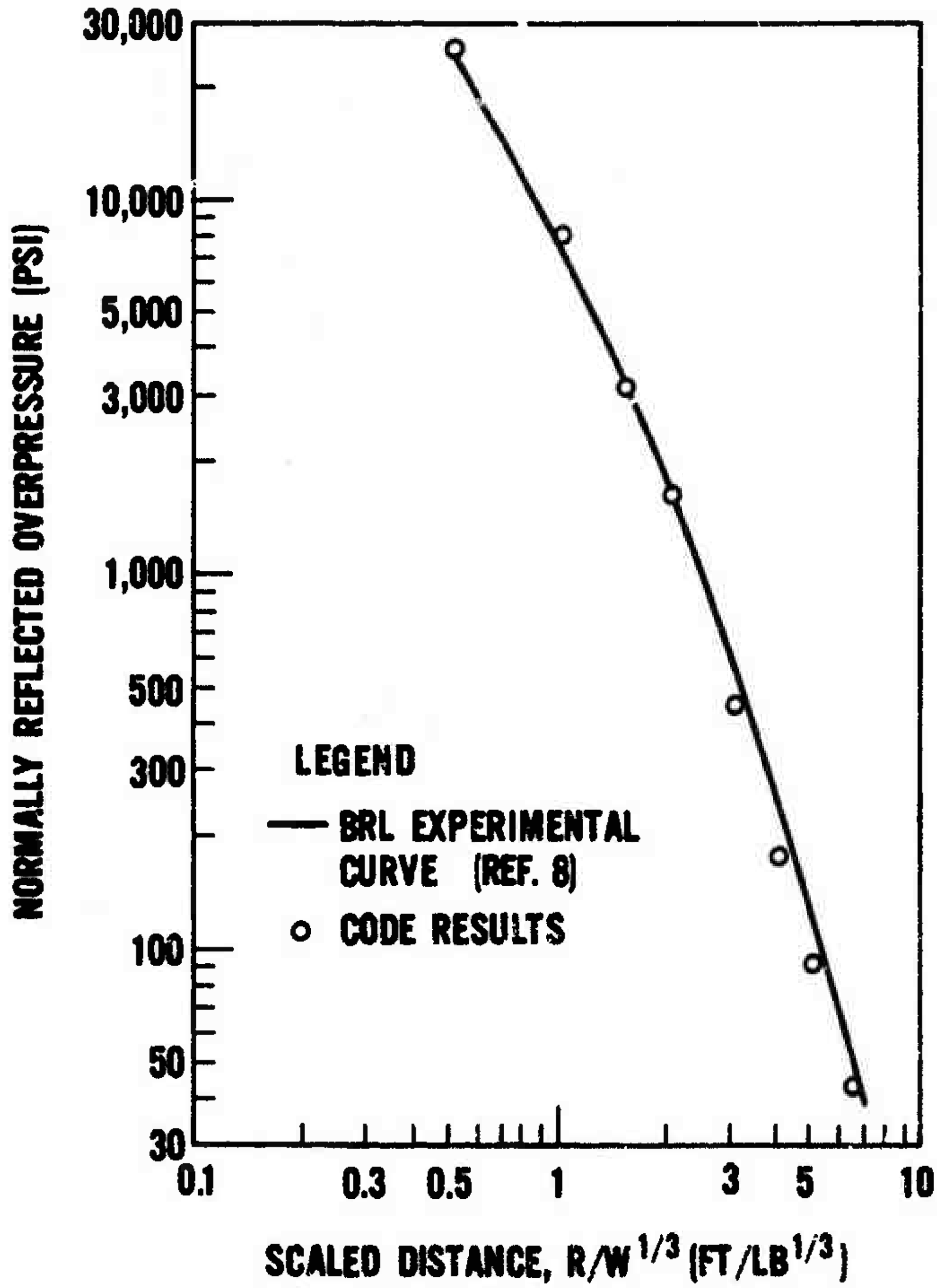

FIG.3 NORMALLY REFLECTED PRESSURE-DISTANCE CURVE FOR PENTOLITE IN AIR AT SEA LEVEL

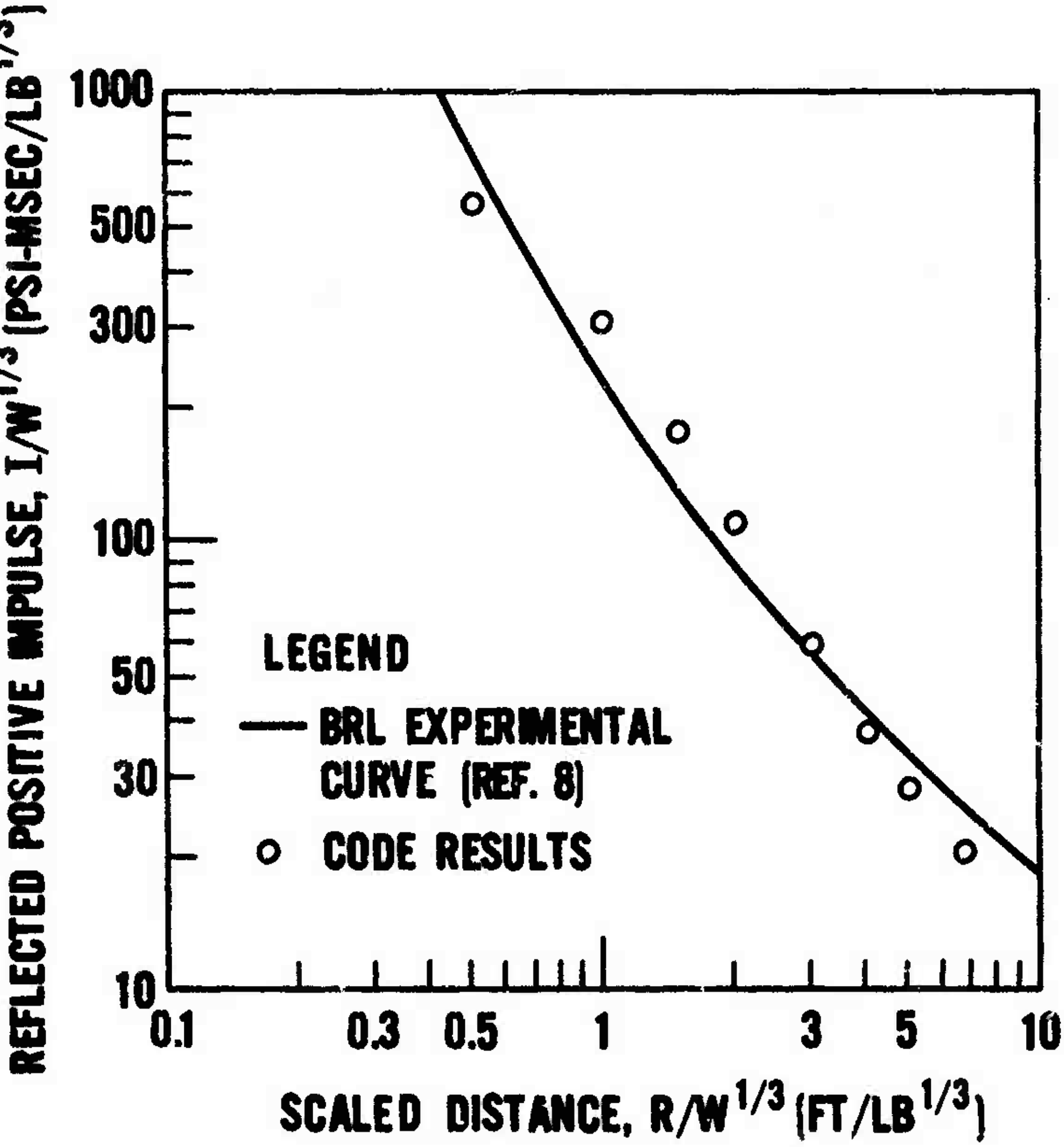

FIG. 4 NORMALLY REFLECTED POSITIVE IMPULSE-DISTANCE CURVE FOR PENTOLITE IN AIR AT SEA LEVEL

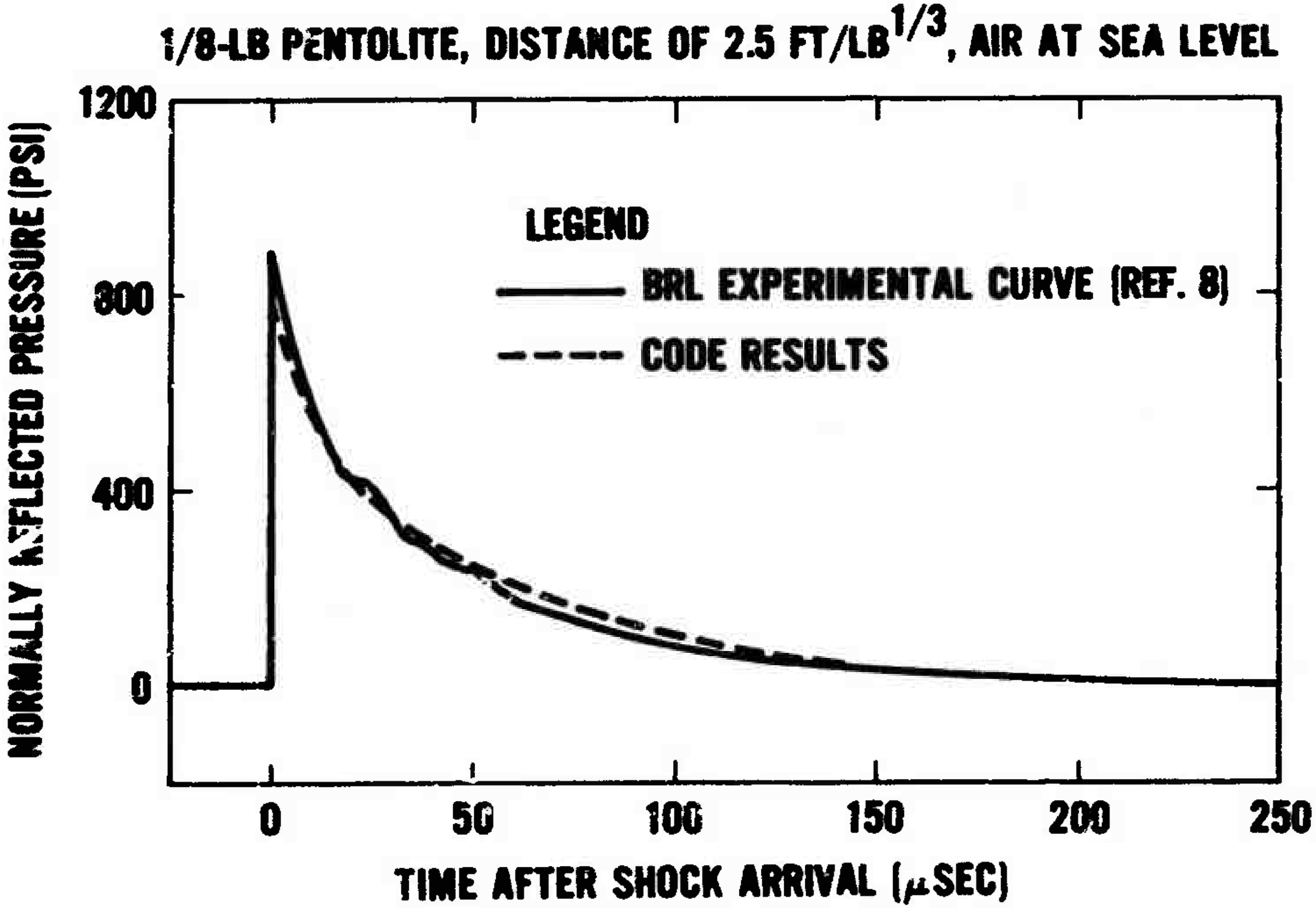

FIG. 5 TYPICAL SHOCK PRESSURE-TIME HISTORY

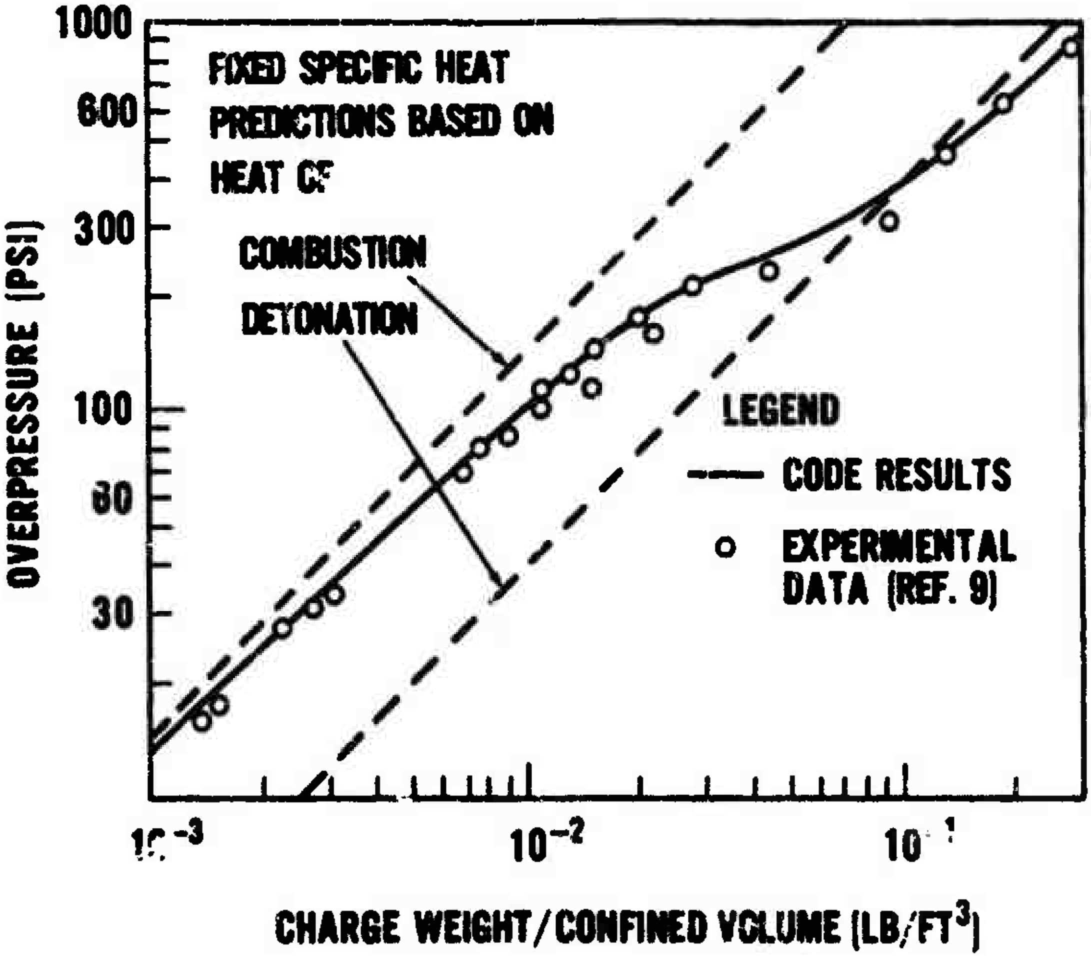

FIG. 6 CONFINED-EXPLOSION GAS PRESSURE FOR TNT IN AIR AT SEA LEVEL

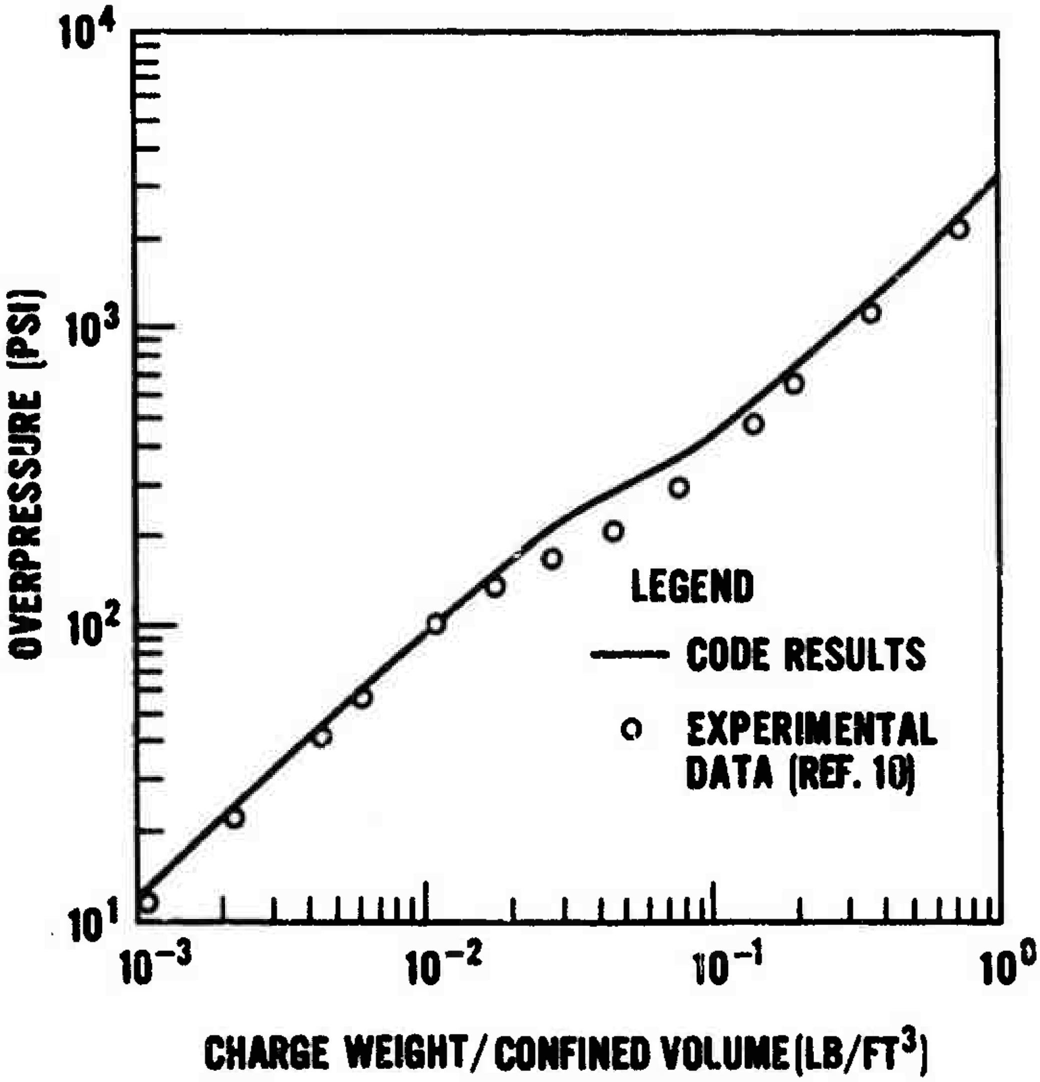

FIG. 7 CONFINED-EXPLOSION GAS PRESSURE FOR RDX/WAX 89.5/10.5 IN AIR AT SEA LEVEL

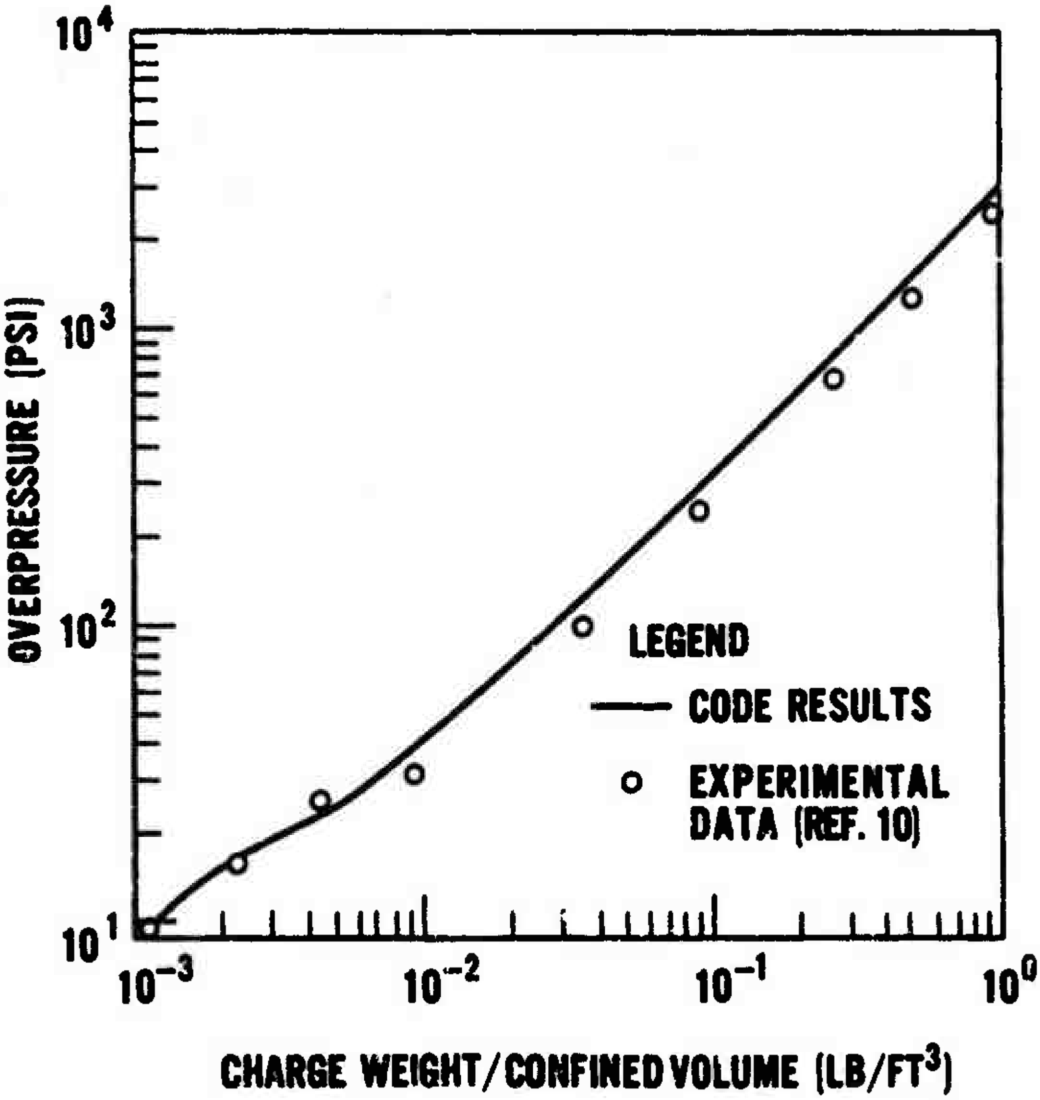

FIG. 8 CONFINED-EXPLOSION GAS PRESSURE FOR RDX/WAX 89.5/10.5 IN AIR AT P = 1 PSI

TYPE OF EXPLOSIVE	W/V (LB/FT^3)	CALCULATED OVERPRESSURE (PSI)	EXPERIMENTAL OVERPRESSURE * (PSI)	DEVIATION (%)
RDX/TNT				
60/40	0.00221	22.0	19.9	+10
60/40	0.00442	41.0	38.3	+ 7
PETN	0.182	711	725	− 2
PETN	0.304	1089	1110	− 2
PETN	0.405	1405	1400	+ 0
RDX/AL/WAX				
98/ 0/2	0.00171	15.3	15.6	− 2
76/22/2	0.00171	22.0	21.3	+ 3
63/35/2	0.00171	26.6	24.3	+ 9
48/50/2	0.00171	30.3	26.0	+16

* RDX/TNT AND PETN ARE FROM REF 10; RDX/AL/WAX FROM REF 1

FIG. 9 MISCELLANEOUS CONFINED-EXPLOSION GAS PRESSURE DATA

```
INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, MAR 1970
NSO/AL/WAO. 74/01/3

EXPLOSIVE PROPERTIES
NUMBER DENT    EFORM EXPLOSIVE COMPOSITION BY WEIGHT
               KCAL/G     C      H      N      O     AL
  17  1.800 .029360  .163  .057  .030  .300  .010
CHARGE SHAPE CORRECTION IS CRUDE.  PSI EXCEEDS
RANGE OF EXPERIMENTAL DATA.

SHOCK WAVE CALCULATION

INPUT PARAMETERS                                 CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)        =   .29450-01           ADJUSTED WT(LB TNT)   =   .45100-01
EXPLOSIVE NUMBER         =    17                 HE ENERGY FACTOR      =   1.900
L/D RATIO                =   0.700               CHARGE SHAPE FACTOR   =   0.866
CASE/CHARGE WT RATIO     =   0.040               CASE WEIGHT FACTOR    =   .8711
CHAMBER PRESSURE(PSIA)=      14.70               PRESSURE SCALE FACTOR=    .9907
CHAMBER TEMP(C)          =   20.00               DISTANCE SCALE FACTOR=    0.010
ALTITUDE (KFT)           =  5.                   TIME SCALE FACTOR     =   0.786
                                                 NORMAL REFL FACTOR    =   0.331

DESIRED DISTANCE(FT)   =    .0670
               (CM)    =   50.83

 TIME AFTER  TIME AFTER   INCIDENT   NORM REFL
 EXPLOSION   SHOCK ARR   OVERPRESS   OVERPRESS
  (MSEC)      (MSEC)       (PSI)       (PSI)
 7.6513E-05  0.            251.7       1590.
   .1029     0.3902E-05    70.38       504.1
   .1145     3.3372E-00    30.05       317.7
   .1000     4.7963E-00    55.03       806.5
   .1308     3.09540-00    51.03       134.9
   .1303     7.1945E-00    15.00       86.95
   .1626     8.3934E-00    5.433       53.00
   .1764     9.0927E-05    0.357       29.77
   .1044      .1570        1.377       15.33
   .1984      .1199       0.          0.

IMPULSE (PSI,MSEC)--
     INCIDENT =   3.055
     REFLECTED=   38.83

CAUTION--CONTACT SURFACE HAS ARRIVED.
   DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL=  4.1045E-02
```

FIG. 10 TYPICAL SHOCK CALCULATION OUTPUT

```
INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, NSD 1975
RDX/AL/WAX, 74/21/9

EXPLOSIVE PROPERTIES
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G     C     H     N     O    AL
  17  1.300 .059360   .163  .027  .200  .250  .215

VENTING CALCULATION

CHARGE WEIGHT(LB)        =   .29402-01
INIT VOLUME(CU FT)       =   5.000
INIT VENT AREA(SQ FT)    =   .8450E-05
AMBIENT PRESSURE(PSIA)   =   14.70
AMBIENT TEMP(C)          =   20.00
CHAMBER PRESSURE(PSIA)   =   14.70
CHAMBER TEMP(C)          =   20.00
NOPT=  1  NV=  3

BEGIN VENTING CALCULATION

TABLE OF VOLUME AND VENT AREA CHANGES
  P(PSIA)      T(SEC)       V(CU FT)      A(SQ FT)     PAMB(PSIA)   TAMB(C) NOPTV
   65.00       .1505        4.550         .54552-05    14.70         20.00      3
   25.00       .0055        4.500         .54502-02    14.70         20.00      3
   19.00       .0500        4.000        0.            14.70         20.60      2


PROPERTIES OF GASES--
OXIDATION COMPLETE
TEMPERATURE, DEGREES F  =  1653.2
ENERGY RELEASE(KCAL/G)  =  2.4572
SPECIFIC HEAT RATIO     =  1.2141
GAS OVERPRESSURE(PSI)   =  45.965

BEGIN VENTING OF GASES
OVERPR(PSI)  TIME(SEC)       GASES(LB)     TEMP(F)     GAMMA NEQN
   45.94      0.             .6167         2112.       1.3141
   41.35       .6926E-01     .5555         2074.       1.2195    1
   36.74       .1452         .5443         5532.       1.3167    1
   36.45       .1505         .5452         2029.       1.3159    1
TIME HAS REACHED TV( 1)=     .1505

FAILURE LEVEL IN TABLE EXCEEDED.
VOLUME INCREASE(CU FT)=   4.555
NEW TOT VOL (CU FT)    =   12.55
NEW TOT AREA (SQ FT)   =   .10902-01
NEW PRESSURE(PSIA)     =   36.75
NEW GAMMA              =   1.342
   22.05          .1505         .8417           1400.       1.3420    1
   19.59          .1504         .7035           1275.       1.2454    1
   17.64          .0564         .7654           1355.       1.2470    1
   15.44          .3056         .7564           1320.       1.3492    1
   13.53          .3674         .6566           1304.       1.3500    1
   12.59          .3821         .5760           1550.       1.3513    1
   10.49          .4515         .4261           1275.       1.3030    2
    8.203         .5273         .5545           1540.       1.3250    2
    6.425         .5005         .9507           1212.       1.3570    2
TIME HAS REACHED TV( 2)=    .6000

FAILURE LEVEL IN TABLE EXCEEDED.
VOLUME INCREASE(CU FT)=   4.055
NEW TOT VOL (CU FT)    =   16.05
NEW TOT AREA (SQ FT)   =   .1625E-51
NEW PRESSURE(PSIA)     =   17.00
NEW GAMMA              =   1.255
   2.258          .5500         .5552           545.7       1.3054    2
   2.122          .6170         .5496           545.4       1.3050    2
   1.556          .6351         .8415           542.1       1.3082    2
   1.651          .6562         .0326           536.7       1.3058    2
   1.619          .6755         .2537           535.3       1.3222    2
   1.175          .0576         .4151           531.9       1.3051    2
    .5431         .7226         .8063           525.4       1.3494    2
    .7574         .7011         .7575           554.5       1.3457    2
    .4716         .7055         .7550           551.2       1.3900    2
    .5358         .2256         .7799           517.7       1.3903    2
    .5250E-51     .5054         .7715           014.4       1.3904    2
```

FIG. 11 TYPICAL VENTING CALCULATION OUTPUT

EFFECTS OF VENTING AND FRANGIBILITY
ON BLAST ENVIRONMENT FROM EXPLOSIONS IN CUBICLES

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INTRODUCTION

The U. S. Army Munitions Command is modernizing ammunition facilities, including equipment and protective structures, used in the manufacture, processing, and storage of conventional munitions. Consistent with new safety regulations, those structures which serve to prevent explosion propagation, damage to material, or injury to personnel are being designed to comply with criteria and methods set forth in NAVFAC P-397 Manual, *Structures to Resist the Effects of Accidental Explosions.*[1] The manual contains procedures and criteria to establish the output from an explosion in its environment and its effects on that environment in terms of blast and fragments.

In using the manual for the modernization program, it was found that certain information was not available while other information required extensive extrapolation of data. One such deficiency is information on the effects of venting and frangibility on the internal and external pressures from explosions in cubicles. Consequently, Picatinny Arsenal (Manufacturing Technology Directorate), Dover, New Jersey, is sponsoring tests at NCEL (Naval Civil Engineering Laboratory) to study the effects of venting and frangibility. Ammann and Whitney, Consulting Structural Engineers, New York, under contract to Picatinny Arsenal, is providing technical guidance in the study.

OBJECTIVE

The overall objective of the study is to establish procedures and criteria for predicting the effects of venting and/or frangibility on the blast environment inside and outside of a cubicle containing an explosion. Specific objectives are (1) to determine the vent area needed to classify a cubicle as fully vented (no gas pressure buildup in cubicle), (2) to delineate the blast environment associated with partially vented cubicles, (3) to define and quantify parameters which describe a frangible cover over a vented cubicle (no amplification from the cover to the blast environment inside the cubicle), and (4) to delineate the blast environment inside a vented cubicle with a semifrangible cover (one that amplifies the blast environment inside a vented cubicle).

This paper deals with the effects of venting. The effects of frangibility are presently being studied at NCEL and will be the subject of another paper.

DESIGN OF EXPERIMENT

Cylindrical charges of Composition B were exploded inside a four-wall steel cubicle. The top or roof of the cubicle was placed flush with the ground surface. Pressures produced by the explosion were measured on interior walls of the cubicle and on the ground surface outside the cubicle at various distances from the charge (Figure 1).

Cubicle

The cubicle was constructed of 3-inch-thick steel plate (Figure 2). Interior plan dimensions of the cubicle measured 2 feet wide by 2 feet long. The open top cubicle (no roof) was 2 feet deep, providing a chamber volume, V, of 8.0 ft^3 and a vent area, A, of 4.0 ft^2.* The vent area of the cubicle was reduced by bolting a 3-inch-thick steel plate over the top of the cubicle. The roof plate had a square vent hole at its center measuring 0.815 by 0.815 ft. The roof plate reduced the chamber depth to 1 ft 9 in., the chamber volume to 7.00 ft^3, and the vent area to 0.667 ft^2. A plate was bolted to the underside of the roof to achieve still smaller vent areas. This plate reduced the chamber volume to 6.91 ft^3 for vent areas of 0.216 and 0.072 ft^2. Critical parameters describing the cubicle are listed in Table 1.

The cubicle was buried in the ground with the top or roof of the cubicle flush with the ground surface. The exterior ground surface was leveled and covered with steel plates to provide a smooth, flat, level surface out to a distance of 53 feet from the cubicle.

Charges

The charges were cast cylinders of Composition B having a length-to-diameter ratio of 1.0 (Figure 2). The charges were cast in long cylinders and then cut and machined to size. The charge was detonated by an engineers special blasting cap (Type J2) placed in a 5/16-inch diameter hole drilled into one end of the cylinder to middepth of the charge. A 0.25 by 0.25-in. cylindrical booster pellet of PBXN-5 was placed in the hole below the cap to insure high order detonation. The combined charge weight of the booster pellet and

* The letter symbols in this paper are defined where they first appear in the text and are arranged alphabetically, for convenience of reference, in the List of Symbols.

blasting cap was never greater than 0.56% of the total charge weight. The charge weights, W, were 0.50, 1.00, 1.50, 2.00 and 3.00 lb ± 1%. Critical parameters describing the charges are listed in Table 1.

The cylindrical charge was oriented with its longitudinal axis in a vertical plane and its center of gravity at the geometric center of the cubicle. The charge was held in position by a string saddle suspended from the roof of the cubicle.

Instrumentation

Pressure transducers were located in each wall of the cubicle and at 2, 4, 8, 16, 32, and 50 ft from ground zero along each of two gage lines 90 degrees apart (Figure 2). The transducers were mounted in steel jackets which were encased in 1 ft^3 of concrete. The pressure transducers were Bytrex HFG piezoresistive type which are specifically designed to measure blast phenomena. The gages are equipped with a heat shield to protect the diaphragm and semiconductor strain gage sensors from radiant heat input, hot gases, and flying particles.

Transducers located inside the cubicle were designed to accurately measure gas pressures, not peak shock pressures. The shock pressures inside the cubicle were several times greater than the chamber gas pressures, that is, 9,000 versus 200 psi. Therefore, shields had to be placed over the gage diaphragm to isolate peak shock pressures while the gage sensitivity was adjusted to accurately measure peak gas pressures.

The signals from the transducers were passed through Endevco Models 4401 and 4470 signal conditioners, Dana Models 3850V2 and 4472-6 amplifiers, and recorded by a Sangamo Saber 4 tape recorder. The recording system was capable of flat response to 40 kHz. A programmable sequence control timer detonated the charge and operated the recording system.

The pressure data was digitized using an FR Model 1400 tape recorder, EMR Model 4143 proportional band width discriminators, and an Electronic Engineering Company high speed digitizer. Impulse profiles were produced with a Wyle Laboratories digital spectrum analyzer.

Digitized pressure and impulse data were sampled at 160 samples per millisecond and plotted using an IBM 7094 computer and SC 4020 plotter.

TEST RESULTS

Typical computerized data outputs plotting pressure and impulse against time at each transducer are shown in Figures 3, 4 and 5. Significant data values, including peak pressure, arrival time of shock front, positive

duration pressura, positive peak impulse, total impulse, test paremeters and weather conditions, ara displayed on the plots by tha computer. Figure 3 is a typical plot of pressures outside tha cubicla at renges of 16, 32, and 50 ft from a 1.0 lb charga along tha south (S) and east (E) gage lines. A second plot is produced for each gaga similar to Figuras 4 and 5, which plot pressure and impulse against time. Figure 4 happens to represent a transducer outside the cubicle located 32 ft from a 1.0-lb charge. Figure 5 is a similer plot from a gage located inside the cubicle (at midheight of the wall) for the explosion of a 0.50-lb charge.

Some pertinent data from the tests are summarized in Table 1. Each reported data point is an average value from about 10 measurements. Unfortunataly, impulse valuas are not listed since all impulse plots were not completed when this paper was prepared.

ANALYSIS OF DATA

Peak Pressures Outside Cubicle

The measured peak side-on overpressure, P_{so}, outside the cubicla is plotted against scaled distence from the charge, $R/W^{1/3}$, in Figures 6-9. The data in Figures 6-9 are for fixed retios of vent area to cubicle volume, A/V, which were 0.500 (open top cube), 0.031, 0.095, end 0.0104 ft^2/ft^3, respectively. Note that all data points for a fixed A/V ratio fall within 30% of a straight-line, best-fit curve of the data. It is significant that the spread in data points about the straight line is as great between points representing the same charge waight to chamber volume, W/V, as between points representing different W/V ratios. From this observation it is concluded that W/V has a negligible effect, if any, on the peak pressures outside a cubicle. For a fixed A/V ratio, the major parameter influencing peak pressures outside a cubicle is $R/W^{1/3}$.

The best fit, straight lines in Figures 6-9 are plotted in Figure 10. As expected, P_{so} decreases with A/V. In other words, raduced venting reduces peak pressures outside a cubicle. From each of these four lines for a fixed A/V ratio, values of P_{so} are plotted in Figure 10 against A/V for fixed values of $R/W^{1/3}$ equal to 2, 10, and 50 $ft/lb^{1/3}$. The shape and relative position of these three lines are significant. First, note that for a fixed $R/W^{1/3}$ the points representing the four ratios of A/V fall on a straight line. Second, the lines are parallel. Third, close inspection shows that the spacing between these straight lines is exactly equal to the logarithm of $R/W^{1/3}$.

The dashed curve in Figure 10 is the relationship between P_{so} and $R/W^{1/3}$ measured at NCEL for unconfined surface bursts of Composition B cylinders.[2] The correlation between this curve and measured data is shown in Figure 11. In Figure 10, the position of this curve for an unconfined surface burst relative to the line for $A/V = 0.500$ (open top cube) is significant. Their reletive position indicates that an open top cubicle with a geometry like the NCEL cubicle does not reduce P_{so} below that for a surface burst at scaled distances greater than about 28. For $R/W^{1/3} > 28$, the only function served by such a cubicle would be to limit primery fragments.

Design Chert for Leakege Pressures

The correlations shown in Figure 10 led to the design chart shown in Figure 12. The chart is useful in selecting the degree of venting (A/V) needed to limit exterior leakage pressures (P_{so}) from a cubicle to some safe level at any distance from the charge or cubicle ($R/W^{1/3}$). A sample problem and solution which serves to illustrate the use of the chart follows.

Problem. It is necessary to protect a frangible building located 100 ft from a cubicle containing 1000 lb of Composition B explosive. The building can safely resist a peak side-on overpressure no greater than 5 psi. Whet vent area is needed in the roof of the cubicle?

Solution. Given W = 1000 lb, R = 100 ft, and P_{so} = 5 psi. Therefore, $R/W^{1/3} = 10$. Entering Figure 12 with $R/W^{1/3} = 10$ and $P_{so} = 5$, one finds $A/V = 0.04\ ft^2/ft^3$. Thus, the required vent area in the roof of the cubicle is $A = 0.04(V)\ ft^2$.

It should be emphasized that the chart in Figure 12 is based on Composition B explosive, not TNT. Further, the chart should be reasonably accurate within the range of the NCEL test parameters, namely for $0.01 < A/V(ft^2/ft^3) < 0.50$, $0.06 < W/V(lb/ft^3) < 0.375$, and $1.5 < R/W^{1/3}(ft/lb^{1/3}) < 70$.

Superimposed on the chart is a curve relating P_{so} and $R/W^{1/3}$ for en unconfined surface burst of Composition B. This curve defines the limiting A/V ratio needed to effectively reduce pressures at any scaled distence. Hence, lines of constant $R/W^{1/3}$ do not increase with vent area for points to the left of the surface burst curve.

A common cubicle design is an open top box. For such a design the ratio A/V is inversely proportional to the wall height. A typical wall is somewhere between 8 and 15 ft high which corresponds to A/V ratios between 0.12 and 0.07 ft^2/ft^3, respectively. Entering Figure 12 with these A/V ratios one concludes that short walls effectively reduce leakage pressures out to a scaled

distance of about 300 ft/lb$^{1/3}$ while tall walls are effective out to scaled distances of about 1,000 ft/lb$^{1/3}$. In both cases, the effectiveness of the cubicle in reducing leakage pressures increases dramatically for points much closer-in to the cubicle.

Full Scale Cubicle Tests

In 1967 the Naval Ordnance Test Station (NOTS), China Lake, California, measured external leakage pressures produced from three explosions in a full scale cubicle.[3] The cubicle was a 3-wall configuration with interior dimensions measuring 40 ft long, 20 ft deep and 10 ft high (Figure 13). The explosive charges in tests 1 and 2 were 2,000- and 3,000-lb spheres of Composition B, respectively. In test 3, the charge consisted of one-hundred 50-lb blocks of TNT, or the equivalent of 4,420 lb of Composition B. The charge in each test was located at the geometric center of the cubicle. External side-on overpressures were measured with BRL gages mounted flush with the ground surface at distences renging from 90 to 1,100 ft from the center of the charge.

External leakage pressures measured along a line normal to a side wall of the NOTS Cubicle are compared with those pressures predicted from the chart in Figure 12 in Table 2 and Figure 14. As illustrated in Figure 14, all measured pressures are within 20% of predicted pressures, and a majority of the values correlate better than 20%. The predicted values are based on a vent area equivalent to the sum of the areas of one "front" wall and roof ($A = 40 \times 20 + 40 \times 10 = 1200$ ft^2). This correlation is quite significant since the NOTS cubicle was much larger than the NCEL cubicle (40-ft versus 2-ft span), the two cubicle configurations are much different (three walls versus four walls), and the charge sizes are vastly different (4,420 lb versus 0.50 lb of Composition B). Considering these large differences, the correlation gives some insight into the validity of the chart in Figure 12 and of applying results from small scale cubicle tests to full-scale structures. Further, the correlation points out the similarities in external leakage pressures from three- end four-wall cubicles.

The correlation is not meant to imply that Figure 12 can be used to predict leakage pressures in front of or behind the backwall of a three-wall cubicle. Here, the blast phenomenon is quite different as described in Reference 3. However, the correlation does mean that Figure 12 can be used to predict leakage pressures along a line normal to either side wall of a three-wall cubicle.

In 1969 the Naval Ordnance Laboratory (NOL), White Oak, Maryland, measured exterior leakage pressures and interior gas pressures produced from explosions in a full scale cubicle.[4] The cubicle is a fully enclosed reinforced

concrete box with a 4 ft wide labyrinth leading out of the chamber (Figure 15). A heavy steel door in the labyrinth closes a 16.6 ft^2 vent area and encloses a total internal cubicle volume of 2,010 ft^3. Charge weights of 1, 2, and 5 lb of pentolite were exploded in the chamber for various amounts of venting (Table 3). The vent area was varied by opening or closing the heavy steel door in the labyrinth passageway. Pressures which leaked out of the cubicle were measured at a point 100 ft from the charge with ARC piezoelectric pencil gages. The magnitude and duration of gas pressures were measured inside the cubicle with CCC variable reluctance gages. Critical test parameters and measured data are listed in Table 3.

External leakage pressures 100 ft from the charge are compared in Table 3 with the leakage pressures predicted from the chart in Figure 12. The correlation is quite good even though the charge density (W/V) and degree of venting (A/V) are much, much smaller than the range of NCEL parameters from which the chart in Figure 12 was constructed. It is concluded that the chart is reasonably accurate (but conservative) in predicting leakage pressures at large scaled distances ($R/W^{1/3} > 100$ ft/lb$^{1/3}$) from cubicles with a low charge density ($W/V < 0.010$ lb/ft^3) and degree of venting ($A/V < 0.010$ ft^2/ft^3).

Gas Pressure Duration Inside a Cubicle

It has been demonstrated that leakage pressures outside a cubicle can be effectively controlled by partially venting the cubicle. This leads to an obvious question concerning the effects of partial venting on the pressure environment inside the cubicle.

The scaled positive phase duration of gas pressure, $t_g/W^{1/3}$, measured inside the cubicle is plotted against the charge weight to chamber volume ratio, W/V, in Figure 16. Included in Figure 16 are data points from other cubicle tests conducted at NCEL by Ferritto.[5] As expected, the duration of gas pressures inside the cubicle increase with decreasing A/V ratios. All data points, representing all W/V ratios, fall within 15% of a straight-line, best-fit curve of the data. The spread in data points about this line is as great between points representing the same W/V ratio as between points representing different W/V ratios. From this observation it is concluded that W/V has a negligible effect, if any, on the duration of gas pressures inside a cubicle. Further, it is concluded that the positive duration of gas pressures inside a cubicle depends solely upon the A/V ratio and charge weight, W. Although scaling t_g by $W^{1/3}$ correlates the NCEL data, the validity of the exponent 1/3 is suspect. The test range of charge weights ($1 \leq W \leq 3$ lbs) is too small to accurately define the exponent; test data is needed at higher charge weights.

There is a knee in the curve at $A/V = 0.10$ ft^2/ft^3. There is really insufficient data to confidently define the curve for $A/V > 0.1$ ft^2/ft^3. In any case, this portion of the curve is important since it ultimately defines the A/V ratio corresponding to a fully vented cubicle.

Gas Pressures Inside a Cubicle

The peak gas pressures, P_{mo}, measured inside the NCEL cubicle are plotted in Figure 17 against the charge density (W/V) for the various degrees of venting (A/V). The gas pressure, P_{mo}, is taken as the mean value found by extrapolating the mean decay curve of pressure back to zero time when the detonation occurred. All data points, regardless of A/V, are within 15% of the best fit, straight line through the data. Further, the spread in data points about the straight line is as great between points representing the same A/V as between points representing different A/V ratios. From this observation it is concluded that A/V has a negligible effect, if any, on the peak gas pressures inside a cubicle. Peak gas pressures in a cubicle depend on the charge density, W/V.

Curves relating peak gas pressures inside a cubicle to charge density are compared in Figure 18. The solid line for Composition B is the straight line in Figure 17 from tests at NCEL. The solid line shown for TNT is the relationship developed by H. Weibull[6] from exploding TNT charges inside spheres, tubes, and cubes. The curve is based on data from relatively small vent areas, $7.6 \times 10^{-6} < A/V(ft^2/ft^3) < 60 \times 10^{-4}$, but from a wide range of charge densities, $0.00125 < W/V(lb/ft^3) < 0.287$. The dashed lines in Figure 18 are based on the energy equation of state for gas which gives the gas pressure produced by the burning of a substance in a fixed volume of air without any heat loss.[7]

$$P_{mo} = 4000\, h_c \left(\frac{W}{V}\right) \tag{1}$$

where P_{mo} = gas pressure, psi

h_c = heat of combustion, kcal/gm (3.62 for TNT; 2.82 for Composition B)

W = charge weight, lb

V = volume of air, ft^3

There is some charge density, W/V (which may be a function of A/V) below which the ambient oxygen concentration is too low to support complete burning of the explosive. As a result, the full heat of combustion is not realized. When this occurs, gas pressures will be lower than predicted by Equation 1.[7] The pressures given by Equation 1 are therefore upper-limit values.

A lower limit value for gas pressure because of incomplete burning of the explosive from a lack of oxygen is given by[7]

$$P_{mo} = 4000\, h_d \left(\frac{W}{V}\right) \tag{2}$$

where h_d = heat of detonation, kcal/gm (1.08 for TNT; 1.24 for Composition B)

From the above discussion it appears that the heat of combustion dictates gas pressures at low charge densities (W/V) while the heat of detonation is the controlling factor for high charge densities, as illustrated by the position of these curves in Figure 18. Between these two limit lines (heat of combustion and heat of detonation lines) is a transition region where P_{mo} versus W/V is described by two solid lines for TNT and Composition B. For a given charge ratio, the NCEL curve would predict a lower gas pressure than Weibull's curve, particularly for larger charge densities. This difference is explained by the facts that (a) the NCEL tests are based on Composition B while Weibull's tests are based on TNT and (b) the NCEL cubicle was 3-inch-thick steel plate construction while Weibull's cubicles were concrete construction. Regarding the later point, the heat loss was probably quite different for the two cubicles (greater for NCEL steel cubicle).

The gas pressures measured in the NOL tests[4] are compared in Table 3 with gas pressures predicted from the Composition B lines in Figure 18. Note that the NOL charge densities are so low ($0.0005 < W/V(lb/ft^3) < 0.0026$) that all points fall on the heat of combustion line in Figure 18. Even so, the correlation is quite good. Based on this correlation, it is recommended that the "heat of combustion" line be used in lieu of extrapolating the solid lines for charge densities less than W/V corresponding to the intersection of the two curves.

Gas to Shock Duration Inside a Cubicle

It has been shown that partial venting results in gas pressures developing inside a cubicle from an explosion. These gas pressures must be considered in design. Their importance depends, in part, on the duration of the gas pressure, t_g, relative to the duration of the shock pressures, t_o, that is, the ratio t_g/t_o. For $t_g/t_o < 1$, a cubicle wall responds solely to the shock loading function. For $t_g/t_o > 1$, the well responds to both the gas and shock loading and the importance of the gas loading increases with t_g/t_o. Therefore, it is useful to delineate the A/V ratio representing a fully vented cubicle ($t_g/t_o < 1$). This requires establishing a relationship between t_g/t_o end A/V.

The gas duration is described in Figure 16, but the relationship for shock duration is not available from NCEL data. The extremely large shock pressures (> 9,000 psi) had to be isolated from pressure transducers inside the cubicle in order to accurately measure the comparatively low gas pressures (< 200 psi). Therefore, t_g/t_o is necessarily based on measured gas durations and computed shock durations (Reference 1). This ratio is more meaningful to the designer because a measured t_o would only apply to the NCEL cubicle while a measured t_g can be related to any four-wall cubicle.

The shock duration on a wall depends on the charge weight and its distance from the nearest and farthest point on the wall.[1] Therefore, shock duration changes radically with charge weight, the aspect ratio of the wall, and the position of the charge relative to the wall. The relationship is greatly simplified for a perfect cube of length, L, with the charge at its geometric center (Figure 19). For this case, the distances to the charge from the nearest and farthest points on any wall are 0.500L and 0.866L, respectively. Since $V = L^3$ for a cube, the scaled distances to the near and far points on any wall are $0.500(V/W)^{1/3}$ and $0.866(V/W)^{1/3}$, respectively. For a given W/V, the scaled distances were computed from the above expressions and used to compute the corresponding scaled shock duration, $t_o/W^{1/3}$, from Reference 1 (Equation 4-1 and Figure 4-5). Results are plotted in Figure 19. Note that $t_o/W^{1/3}$ depends only on W/V for this special case.

Curves in Figures 16 end 19 were combined to construct the chart in Figure 20. Note that t_g/t_o depends on A/V which affects gas duration and on W/V which affects shock duration.

For the NCEL cubicle with en open top, $A/V = 0.50\ ft^2/ft^3$. From Figure 20, $t_g/t_o \leq 1$ provided $W/V < 0.008\ lb/ft^3$. For a larger cube, say 10 ft, with no roof $A/V = 0.10$. For $t_g/t_o \leq 1$ requires $W/V < 0.001\ lb/ft^3$. This would limit the charge weight to less than 1 lb of Composition B for the cube to be fully vented.

Figure 20 in conjunction with Figure 16 can be used to design cubicles which approach a cube shape. A problem to illustrete their use follows.

Problem. A cubicle has a length and width of 2 ft. The height is 1.75 ft. A 0.50-lb charge of Composition B is located at its geometric center The vent area is $0.217\ ft^2$. Find t_g/t_o, t_g and t_o.

Solution. $V = 2 \times 2 \times 1.75 = 7.0$, $A = 0.217$, $W = 0.50$. Therefore, $A/V = 0.031$ and $W/V = 0.072$. From Figure 20, $t_g/t_o = 100$. From Figure 16, $t_g = 44(W)^{1/3} = 35$ msec. So $t_o = t_g/100 = 0.35$ msec. The measured pressure-time plot for this problem is shown in Figure 5. Note thet the measured shock duration is about equal to the predicted value.

Figure 20 shows that the A/V needed to classify a cube as fully vented ($t_g/t_o \leq 1$) depends on W/V. For cubes with short walls (8 ft) the charge density must be very small (W/V < 0.0001 lb/ft^3), and for tall walls (15 ft) the charge density must be even smaller. Practical charge densities are much greater than 0.0001 lb/ft^3. Therefore one concludes that most four-wall cubes, even with open tops, are not fully vented. However, it should be pointed out that according to Figure 17, the gas pressures corresponding to these small charge densities are relatively low. In any case, it appears impractical to design a four-wall cube to be fully vented.

For three-wall cubes with no roof, A/V = 2/L. For this case too, Figure 20 shows that the charge density must be very small to achieve full venting. For this case too, it appears impractical to design a three-wall cube to be fully vented.

Most shock loadings on cubicle walls are very short in duration compared to the fundamental period of the wall, T_n. Therefore, most cubicle walls will feel the shock loading as an impulse ($t_o/T_n < 0.2$) in which case the gas duration can be about 30 times greater than the shock duration ($t_g/t_o = 30$) before the wall feels the gas loading as a long duration load ($t_g/T_n = 6$). According to Figure 20, $t_g/t_o \leq 30$ provided W/V is less than 0.080 and 0.035 lb/ft^3 for short and tall walls, respectively, of open top 4-wall cubes. For three-wall cubes the corresponding charge densities for $t_g/t_o \leq 30$ are about 0.400 and 0.150 lb/ft^3, which begin to approach practical charge densities. From this observation it appears that practical charge densities in three- and four-wall cubes with open tops may generate long-duration loads on the cubicle walls.

CONCLUSIONS

1. Outside the cubicle, the leakage pressures depend on the degree of venting (A/V) and scaled distance to the point of interest ($R/W^{1/3}$). These leakage pressures can be predicted from the chart in Figure 12 for any four-wall cubicle and for three-wall cubicles along lines normal to the side walls.

2. Compared to unconfined surface explosions, four-wall cubicles with open or frangible roofs reduce leakage pressures out to scaled distances of about 300 ft/lb$^{1/3}$ for short walls (8 ft) and 1,000 ft/lb$^{1/3}$ for tall walls (15 ft). For any four-wall cubicle, the effectiveness of its walls in reducing leakage pressures increases dramatically as the point of interest moves closer to the cubicle.

3. Inside the cubicle, the leak area to chamber volume (A/V) and charge weight (W) define the duration of the gas pressures, and the charge density (W/V) determines the peak gas pressure. The gas duration can be predicted from Figure 16 and the gas pressures from Figure 18 for four-wall cubicles with or without an infrangible roof.

4. The vent area (A/V) needed to classify a cubicle as fully vented ($t_g/t_o < 1$) depends on the configuration of the cubicle and the position of the charge within the cubicle. For practical charge densities, most three- and four-wall cubes, even without roofs, are not fully vented and gas pressures should be considered in design. For cubes the ratio t_g/t_o can be predicted from Figure 20 for any W/V and A/V.

FUTURE WORK

Work is continuing at NCEL on venting from three-wall cubicles. Tests are planned to study the effect of cover frangibility on the blast environment inside and outside a cubicle. Paremeters will be defined and quantified to describe a fully frangible, partially frangible and nonfrangible cover over a vent area.

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Richard Rindner of Picatinny Arsenal conceived and administered the study. Norval Dobbs of Ammann and Whitney provided valuable technical guidance during the course of the study. The Pacific Missile Range, Point Mugu, California, provided the test range, detonated the charges, and computerized the data. Their support is greatly appreciated.

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LIST OF SYMBOLS

A	Vent area of the cubicle, ft^2
h	Heat of combustion or heat of detonation, kcal/gm
L	Length, ft
P	Pressure, psi
P_{so}	Peak side-on overpressure, psi
P_{mo}	Peak gas pressure, psi
R	Range from charge to pressure transducer or point of interest, ft
t	Time, msec
t_g	Positive phase duration of the gas pressure, msec
t_o	Positive phase duration of the shock pressure, msec
T_n	Fundamental period of vibration, msec
V	Volume inside of cubicle, ft^3
W	Total weight of explosive, lb

Table 1. Summary of Test Parameters, Exterior Overpressures and Internal Gas Pressures

Cubicle			Charge		Scaled Distance, $R/W^{1/3}$ (ft/lb$^{1/3}$) for a Slant Range to Transducer, R, of —						Peak Side-On Overpressure, P_{so} (psi)[b] for a Slant Range to Transducer, R, of —						Gas Pressure in Cubicle		
A (ft^2)	V (ft^3)	A/V (ft^2/ft^3)	W[a] (lb)	W/V (lb/ft^3)	2.24 Feet	4.12 Feet	8.06 Feet	18 Feet	32 Feet	50 Feet	2.24 Feet	4.12 Feet	8.06 Feet	18 Feet	32 Feet	50 Feet	P_{mo} (psi)	t_g (msec)	$t_g/W^{1/3}$ (msec/lb$^{1/3}$)
4.00[c]	8.00	0.500	0.50	0.063	2.82	5.19	10.2	20.2	40.3	63.0	85	29	17	5.9	1.74	0.72	–	1.5	1.89
			1.50	0.188	1.96	3.60	7.04	14.0	28.0	43.7	129	41	25	8.5	2.90	1.40	–	–	–
			3.00	0.375	1.55	2.86	5.59	11.1	22.4	34.7	215	45	32	12.8	3.25	2.00	–	2.75	1.90
0.667	7.00	0.095	0.50	0.071	2.82	5.19	10.2	20.2	40.3	63.0	33	13.0	7.0	3.2	0.84	0.45	210	15	18.9
			1.00	0.143	2.24	4.12	8.06	16.0	32.0	50.0	43	16.0	10.2	4.2	1.30	0.63	275	18	18.0
			2.00	0.286	1.78	3.27	6.40	12.7	25.4	36.7	53	20.4	13.3	6.3	1.70	0.94	607	20	15.9
0.216	6.91	0.031	0.50	0.072	2.82	5.19	10.2	20.2	40.3	63.0	29	11.4	4.0	2.4	0.59	0.22	210	35	44
			1.00	0.145	2.24	4.12	8.06	18.0	32.0	50.0	30	11.3	7.9	3.4	0.76	0.36	322	44	44
			2.00	0.289	1.78	3.27	6.40	12.7	25.4	39.7	41	15.8	10.7	4.8	1.21	0.56	617	57	45
0.072	6.91	0.010	0.50	0.072	2.82	5.19	10.2	20.2	40.3	33.0	18	7.0	2.8	0.92	0.32	0.12	218	107	135
			1.00	0.145	2.24	4.12	8.06	18.0	32.0	50.0	24	8.4	4.7	1.9	0.44	0.18	315	112	112
			2.00	0.289	1.78	3.27	6.40	12.7	25.4	39.7	39	12.0	6.9	3.5	0.85	0.32	818	129	103

[a] Charge weight accurate to within 0.01 pound.

[b] Average of 10 measurements at each slant range.

[c] Open top cube.

Table 2. Comparison of Measured and Predicted External Leakage Pressure for NOTS Full-Scale Cubicle Tests

Charge Weight, W[a] (lb)	Range to Transducer		Side-On Overpressure, P_{so} (psi)	
	R (ft)	$R/W^{1/3}$ ($ft/lb^{1/3}$)	Measured[b]	Predicted[c]
2,000	90	7.2	17.70	13.0
	150	11.9	7.90	6.4
	230	18.3	3.10	3.5
	340	27.0	1.90	2.0
	510	40.4	1.20	1.2
	740	58.7	0.61	0.66
	1,100	67.3	0.43	0.39
3,000	90	6.2	21.40	16.3
	150	10.4	6.97	7.8
	230	15.9	3.58	4.3
	340	23.6	2.57	2.5
	510	35.4	1.63	1.4
	740	51.3	–	–
	1,100	76.3	0.54	0.48
4,420	90	5.5	20.59	19.1
	150	9.1	10.37	9.2
	230	14.0	3.93	5.0
	340	20.7	3.16	2.9
	510	31.0	1.67	1.65
	740	45.0	1.02	0.98
	1,100	67.0	0.62	0.58

[a] Composition B explosive.

[b] Data taken from Reference 3.

[c] Predicted values taken from Figure 12 for $A/V = 0.15\ ft^2/ft^3$, where $A = (10 \times 40) + (20 \times 40) = 1{,}200\ ft^2$ and $V = 20 \times 40 \times 10 = 8{,}000\ ft^3$.

Table 3. Comparison of Measured and Predicted Blast Environment for NOL Full-Scale Cubicle Tests

Charge, W^a (lb)	Vent, A (ft^2)	Critical Ratios[b]			Measured Values[c]			Predicted Values			
		W/V (lb/ft^3)	A/V (ft^2/ft^3)	$R/W^{1/3}$ ($ft/lb^{1/3}$)	Outside P_{so} (psi)	Inside P_g (psi)	Inside t_g (msec)	Outside $P_{so}{}^d$ (psi)	Inside $P_g{}^e$ (psi)	Inside $t_g{}^f$ (msec)	Inside $t_g/W^{1/3}$ ($msec/lb^{1/3}$)
1.04	16.6	0.0005	0.0083	98.6	0.084	7.3	91	0.101	5.3	147	145
	2.4	0.0005	0.0012	98.6	0.022	6.4	495	0.049	5.3	790	780
	0.0	0.0005	0.0000	98.6	0.006	6.3	2,000	0.000	5.3	∞	∞
2.07	16.6	0.0010	0.0083	78.4	0.149	14.6	136	0.150	12.0	185	145
	2.4	0.0010	0.0012	78.4	0.032	12.9	680	0.072	12.0	995	780
	0.0	0.0010	0.0000	78.4	0.014	12.9	2,670	0.000	12.0	∞	∞
5.18	16.6	0.0026	0.0083	57.8	0.337	31.3	167	0.240	30.0	250	145
	2.4	0.0026	0.0012	57.8	0.068	31.4	1,100	0.110	30.0	1,350	780
	1.2	0.0026	0.0006	57.8	0.022	27.8	3,200	0.081	30.0	2,600	1,500
	0.0	0.0026	0.0000	57.8	0.024	32.6	3,500	0.000	30.0	∞	∞

[a] Composition B (based on TNT equivalencies of Composition B and Pentolite equal to 1.13 and 1.17, respectively).

[b] Volume of cubicle, V = 2,010 ft^3 (Reference 4).

[c] Taken from Reference 4.

[d] From Figure 12.

[e] From Figure 17.

[f] From Figure 16.

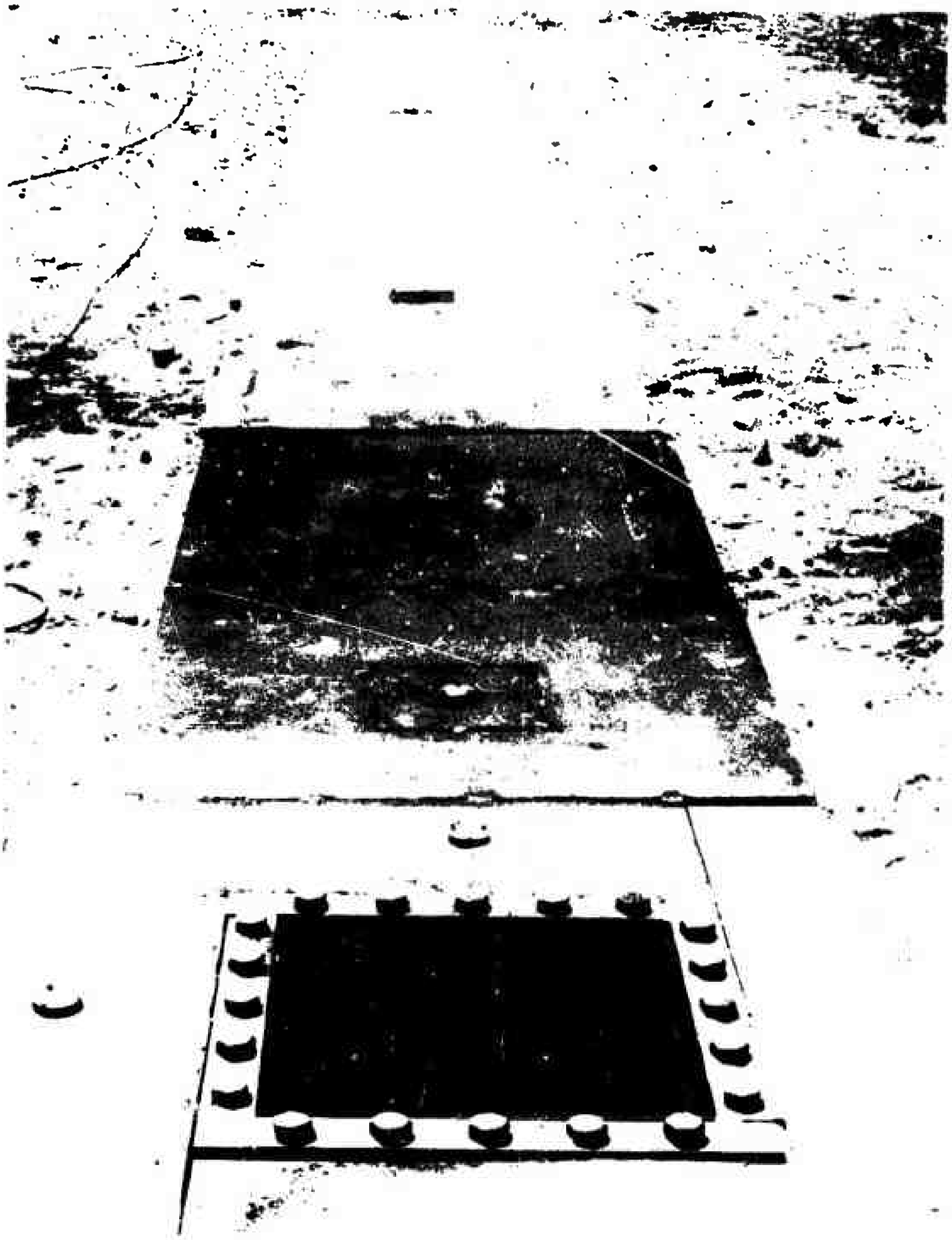


Figure 1. View of test site.

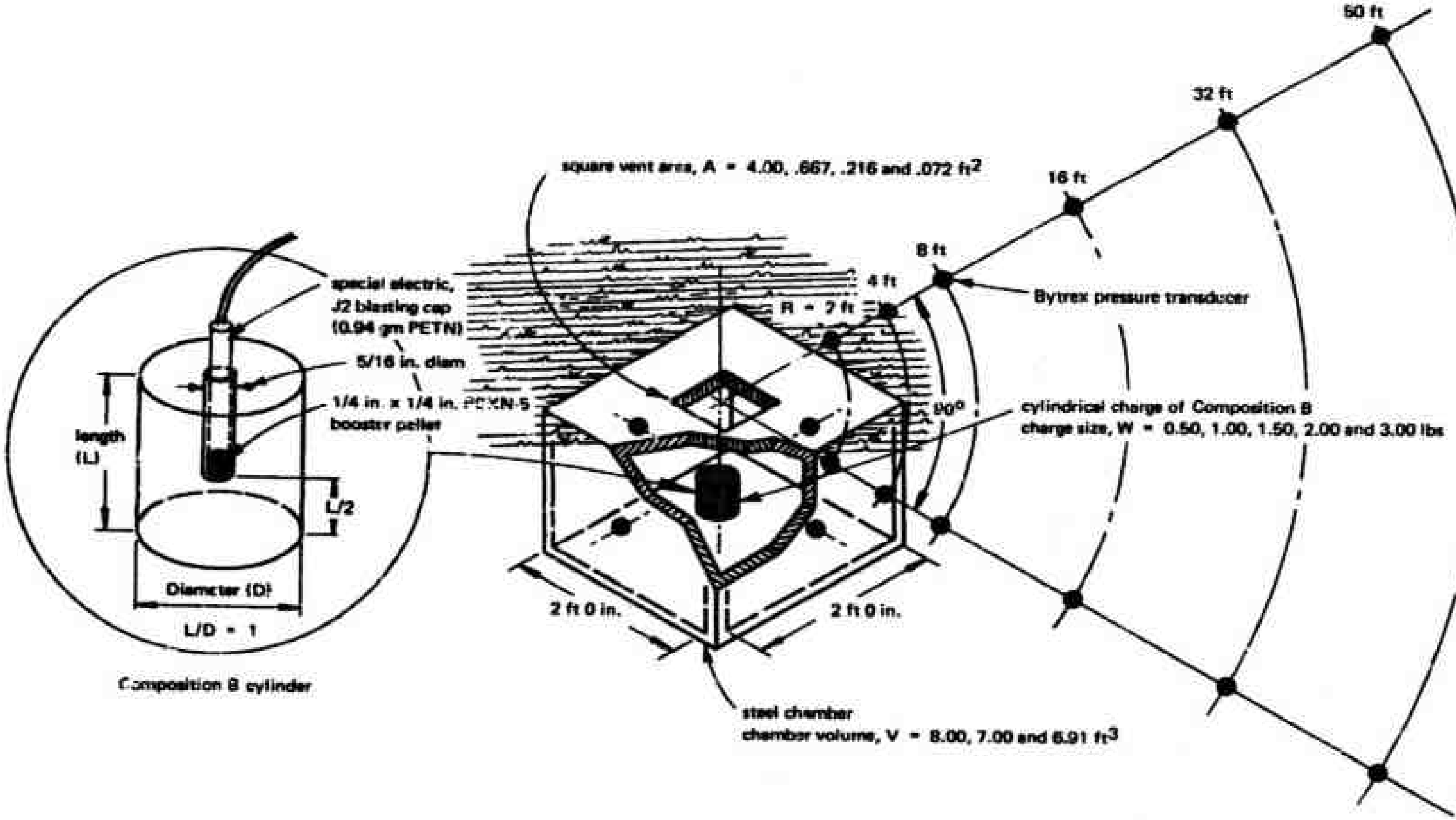


Figure 2. Details of Test Setup.

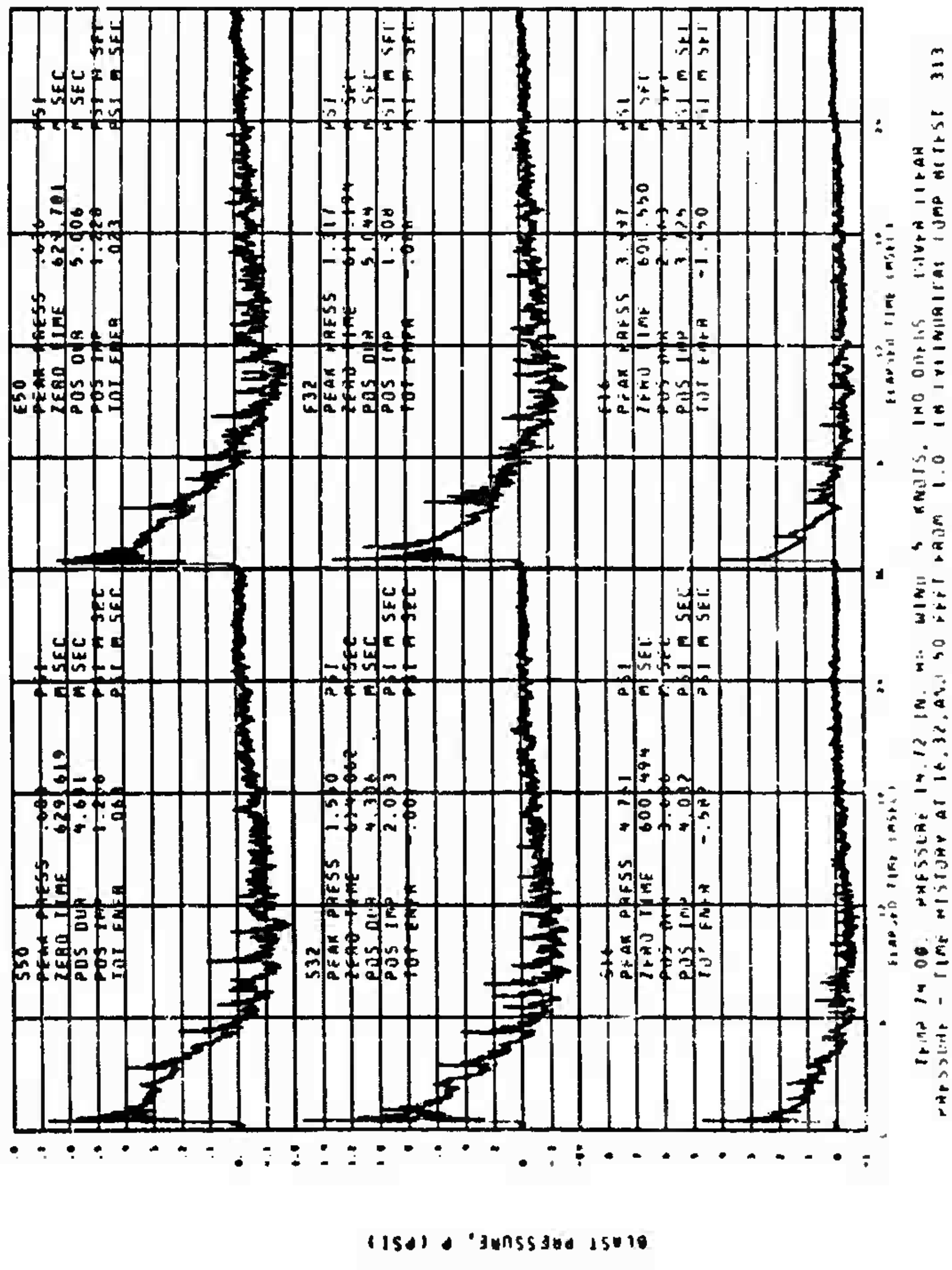


Figure 3. Typical computerized data plot of pressure-time history at 6 points outside of cubicle.

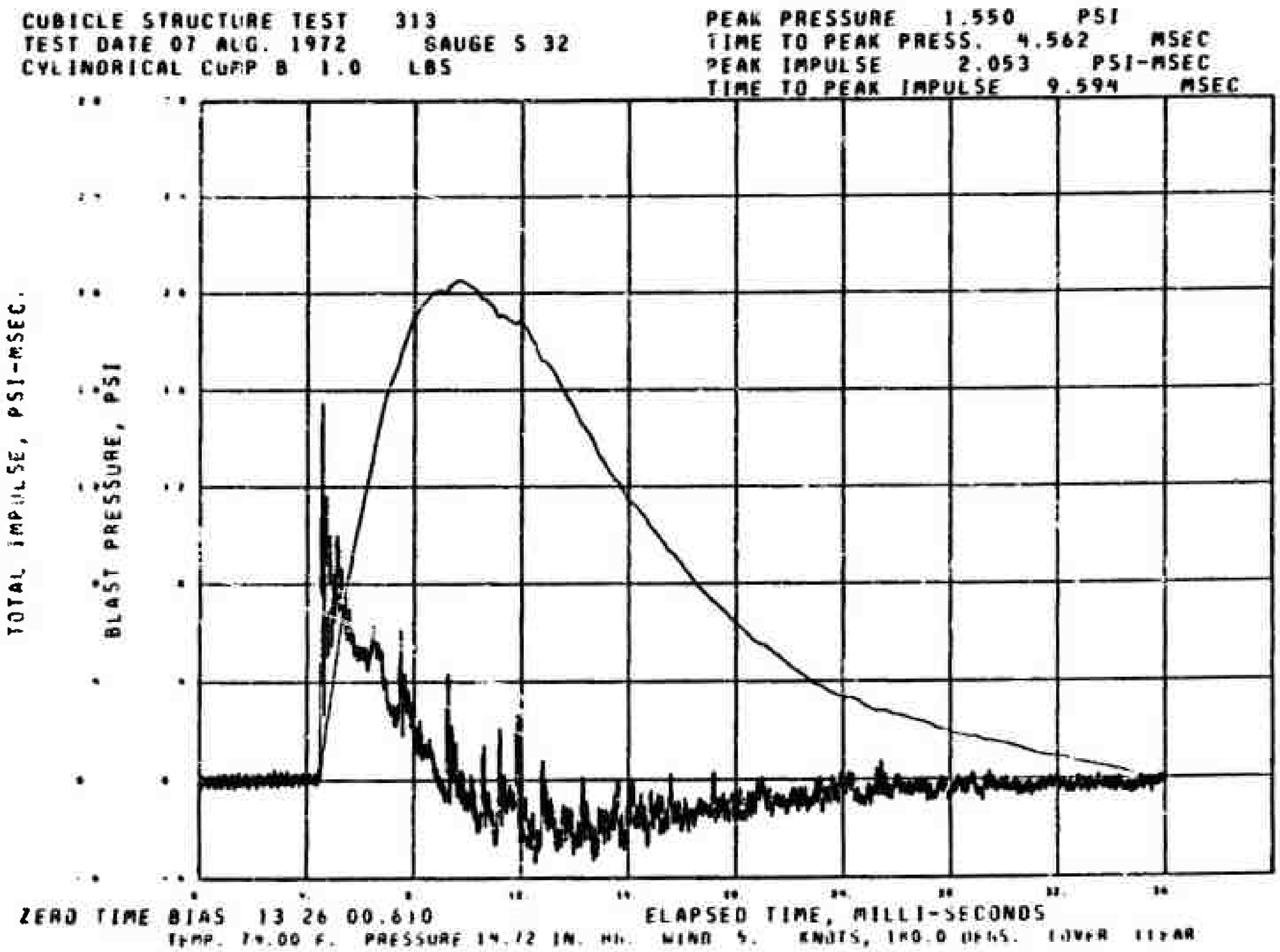


Figure 4. Typical computerized data plot of pressure and impulse-time history at a gage 32 ft from a 1 lb charge.

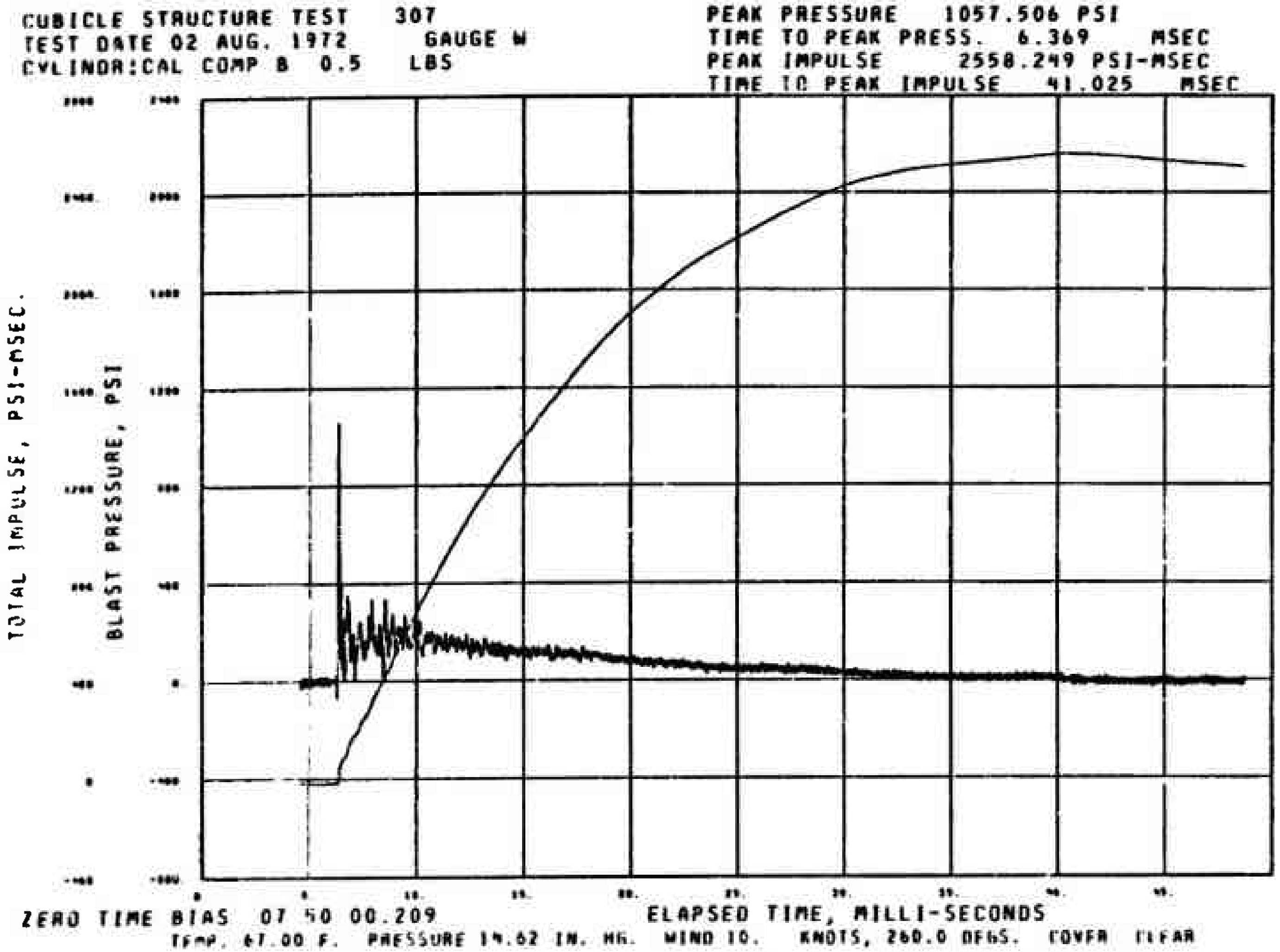


Figure 5. Typical computerized data plot of pressure and impulse-time history at a gage inside cubicle at mid-height of wall.

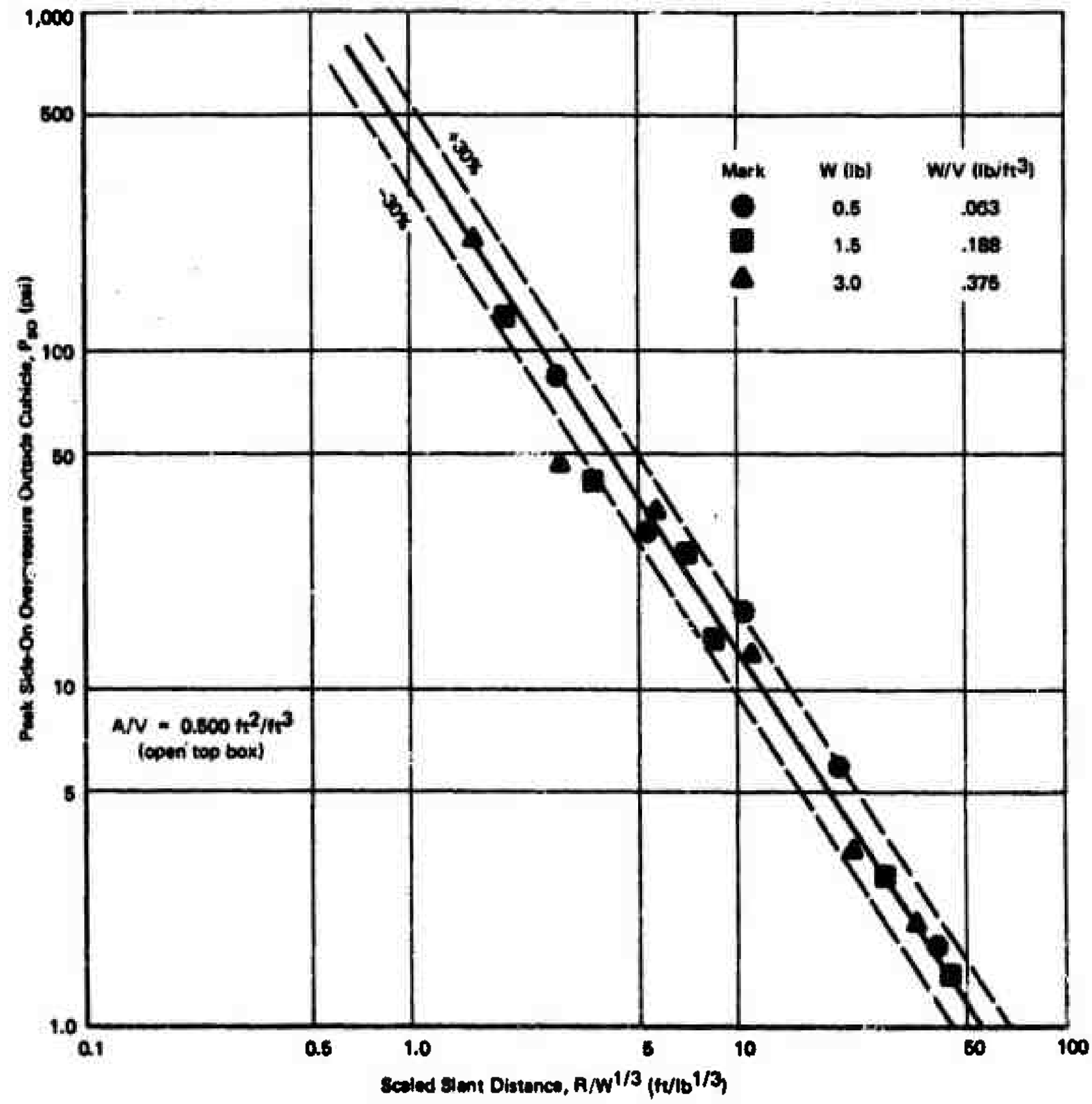


Figure 6. External side-on overpressure versus scaled distance for A/V = 0.500 ft^2/ft^3.

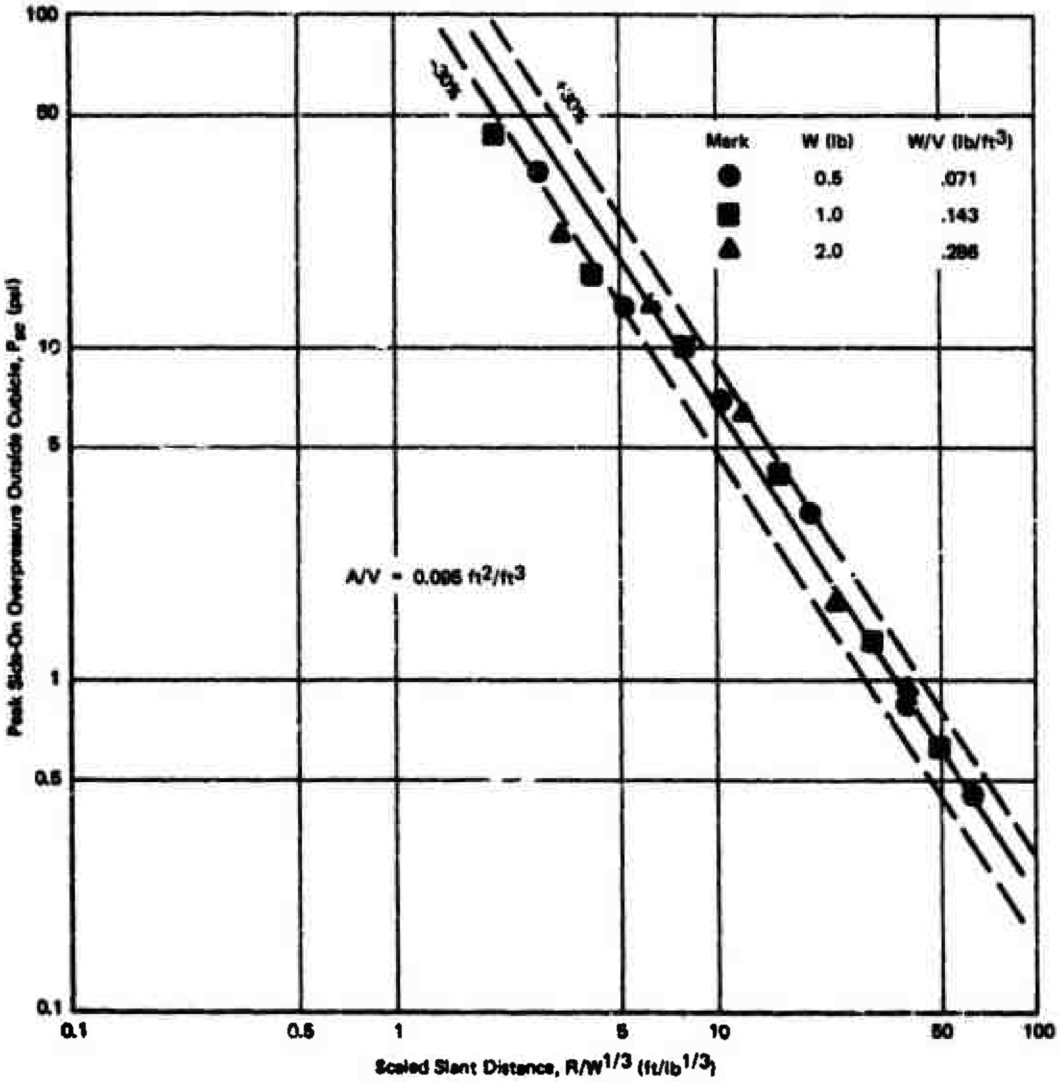


Figure 7. External side-on overpressure versus scaled distance for A/V = 0.095 ft^2/ft^3.

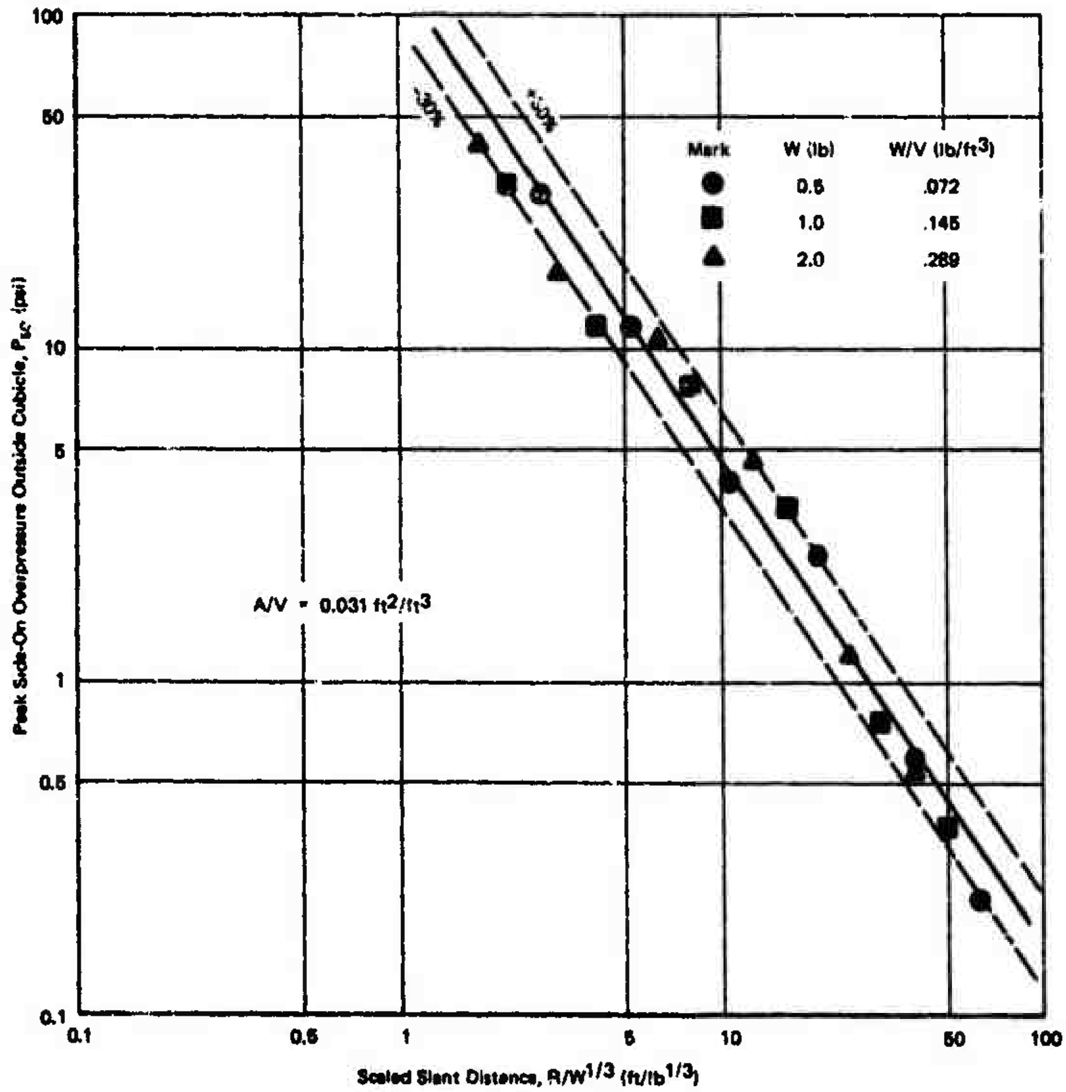


Figure 8. External side-on overpressure versus scaled distance for A/V = 0.031 ft²/ft³.

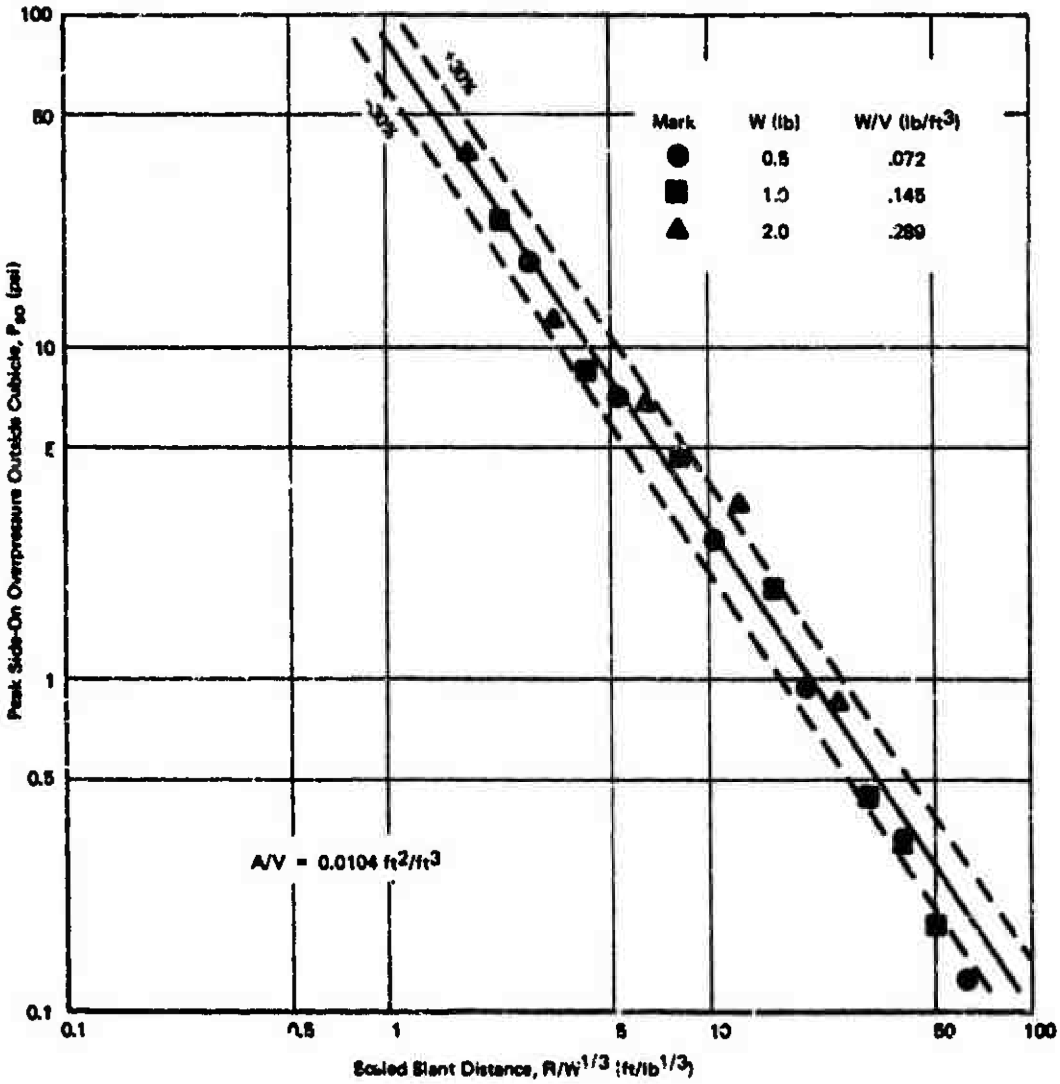


Figure 9. External side-on overpressure versus scaled distance for A/V = 0.0104 ft^2/ft^3.

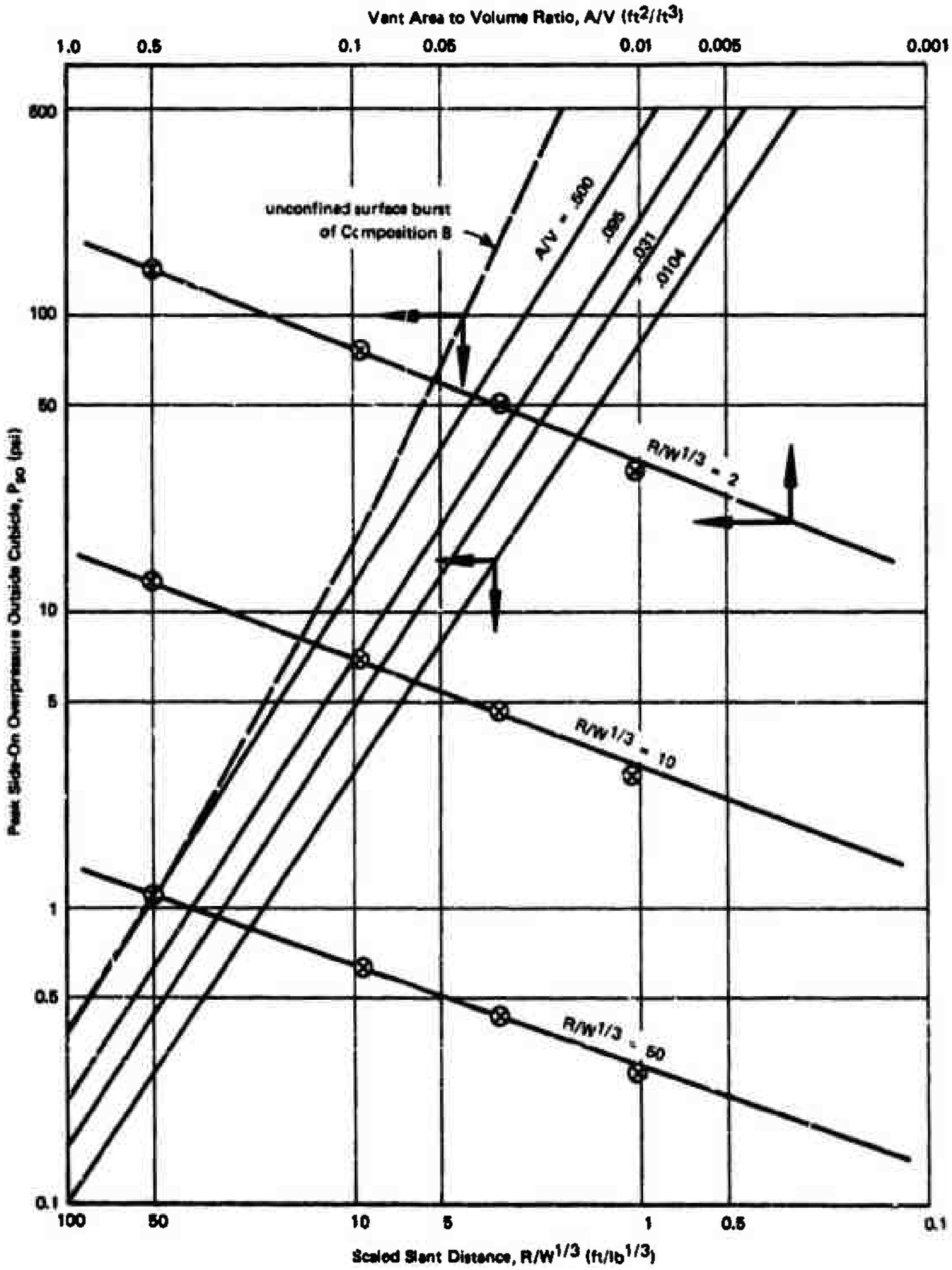


Figure 10. External side-on overpressure versus scaled distance and vent area.

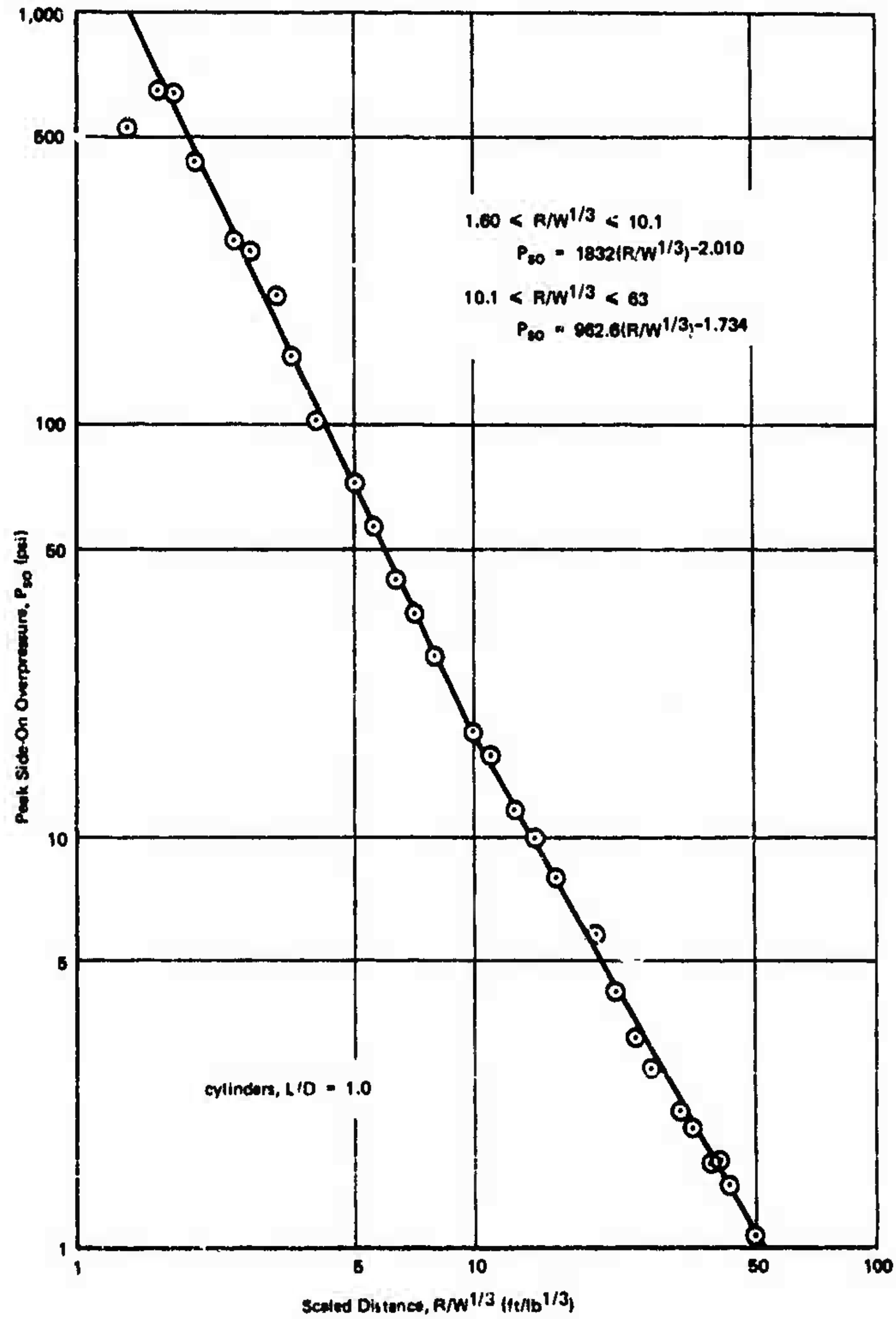


Figure 11. Peak side-on overpressure versus scaled distance for surface burst of composition B cylinders.

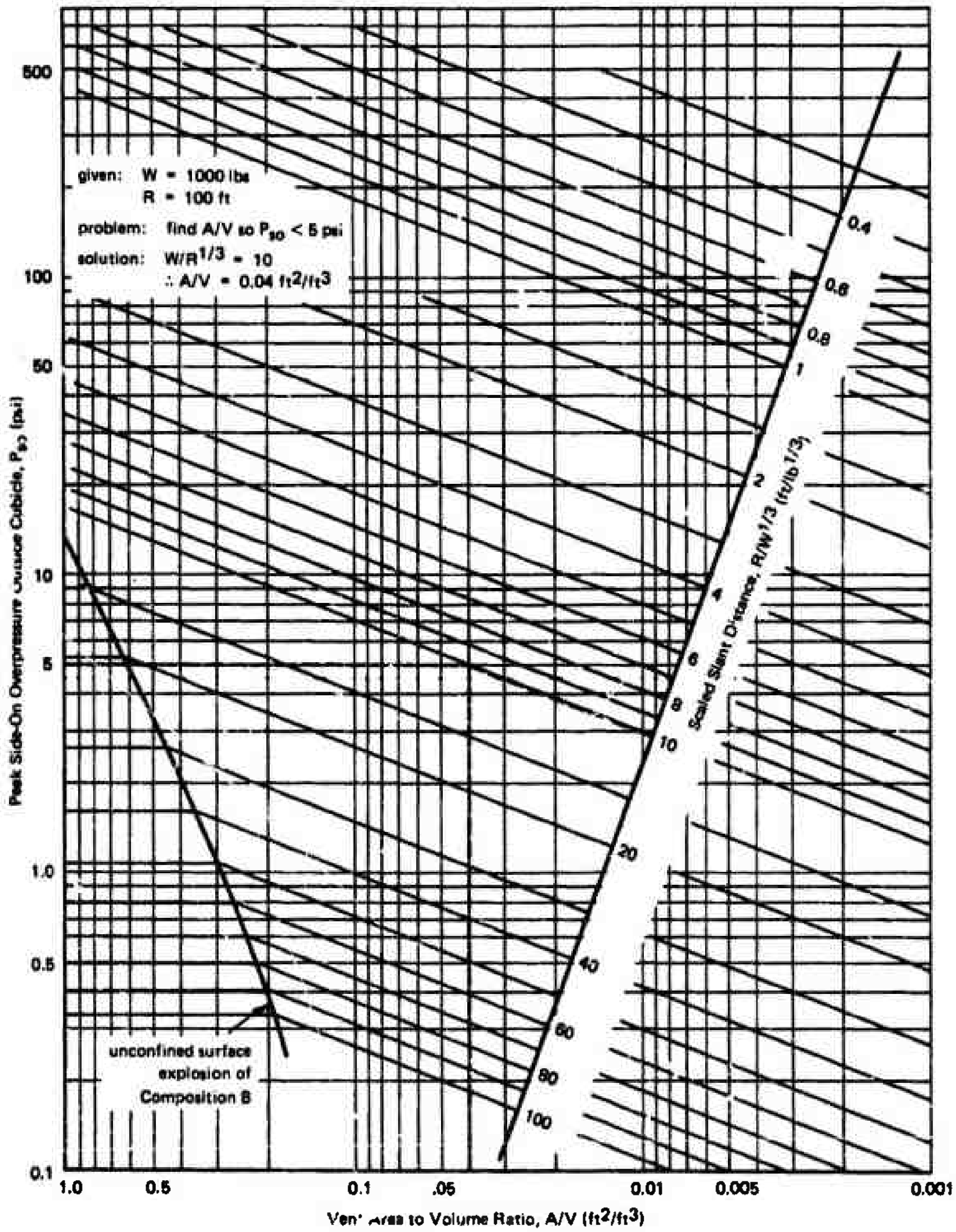


Figure 12. Design chart for vent area required to limit pressures at any range outside a cubicle.

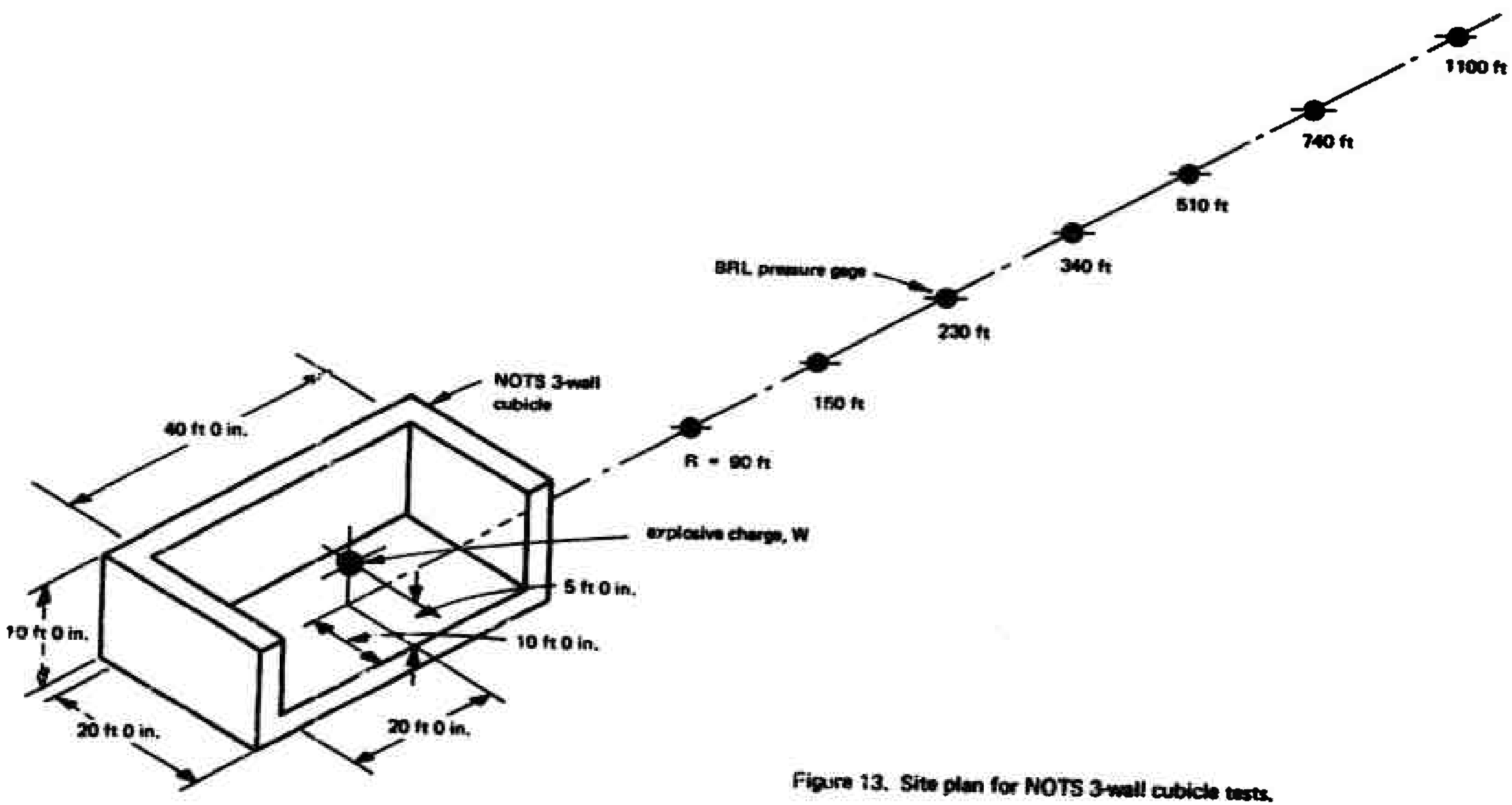


Figure 13. Site plan for NOTS 3-wall cubicle tests.

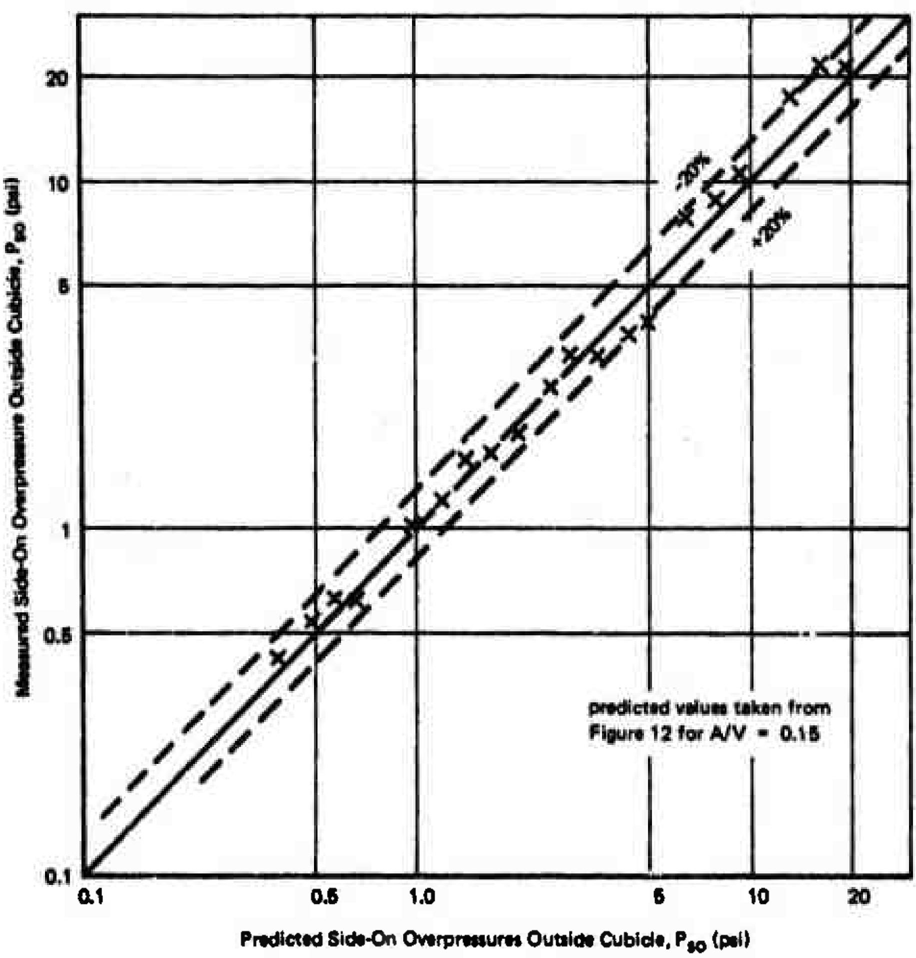


Figure 14. Measured versus predicted side-on overpressures outside NOTS cubicle.

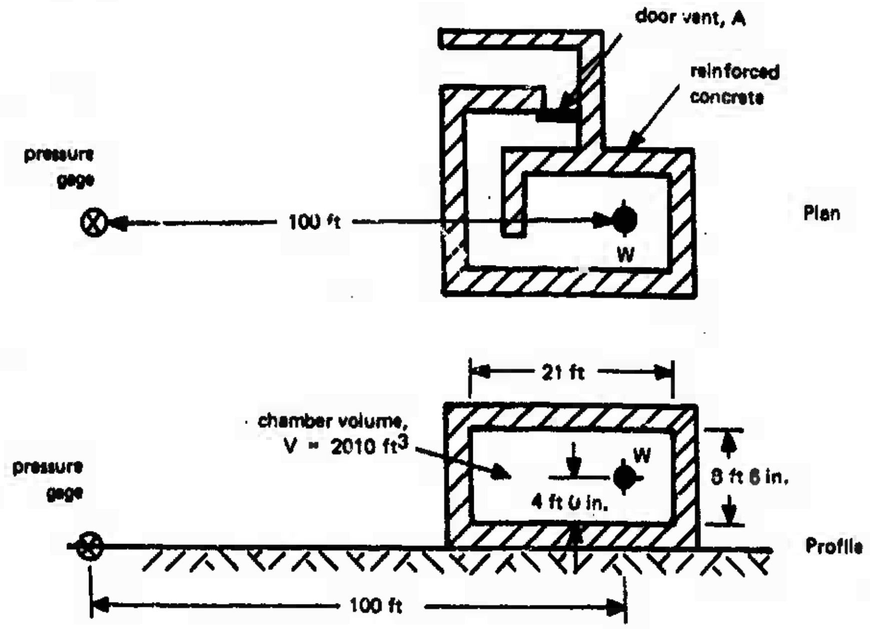


Figure 15. Site details for NOL cubicle tests.

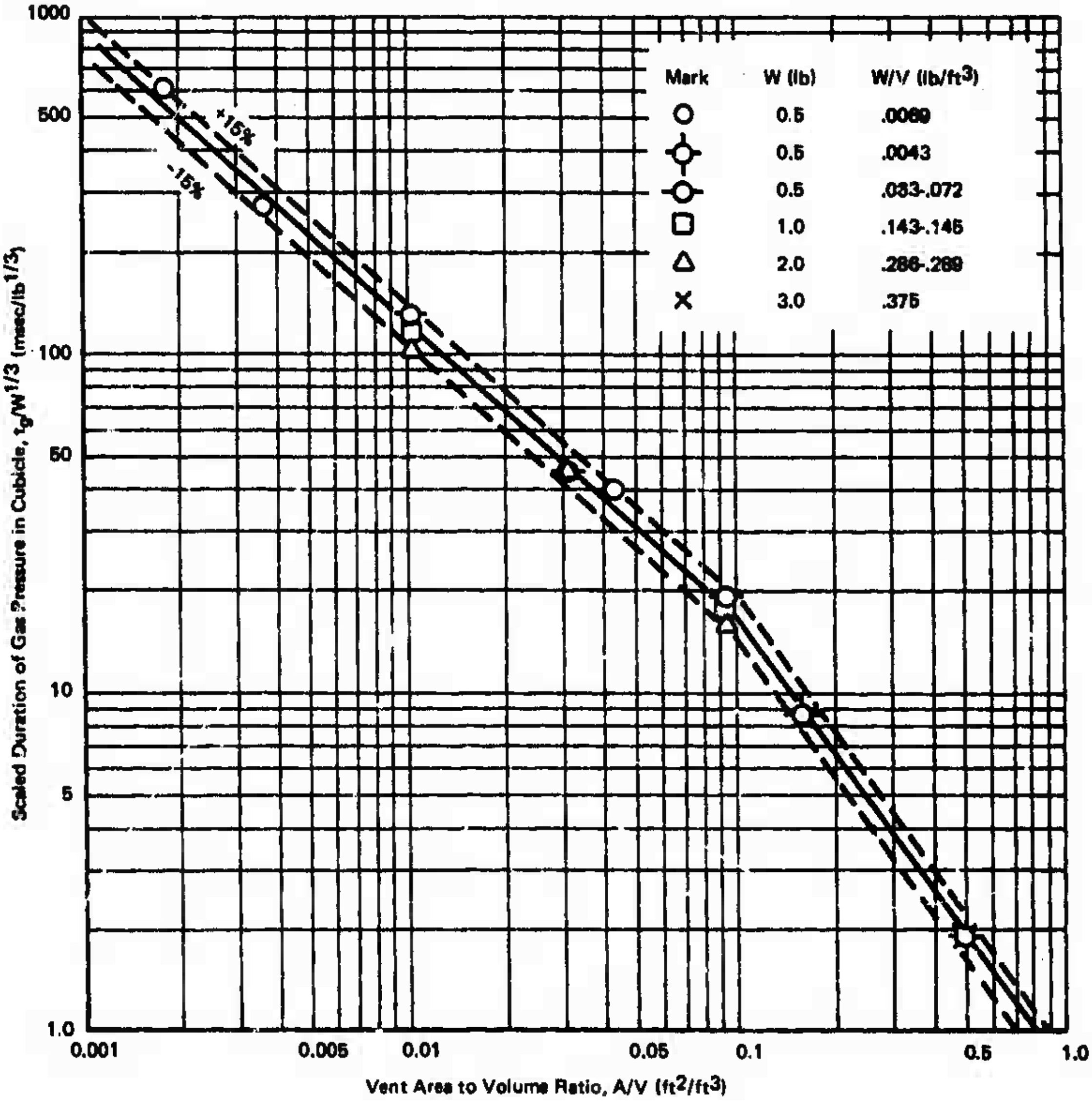


Figure 16. Scaled duration of gas pressure in cubicle versus vent area to volume ratio.

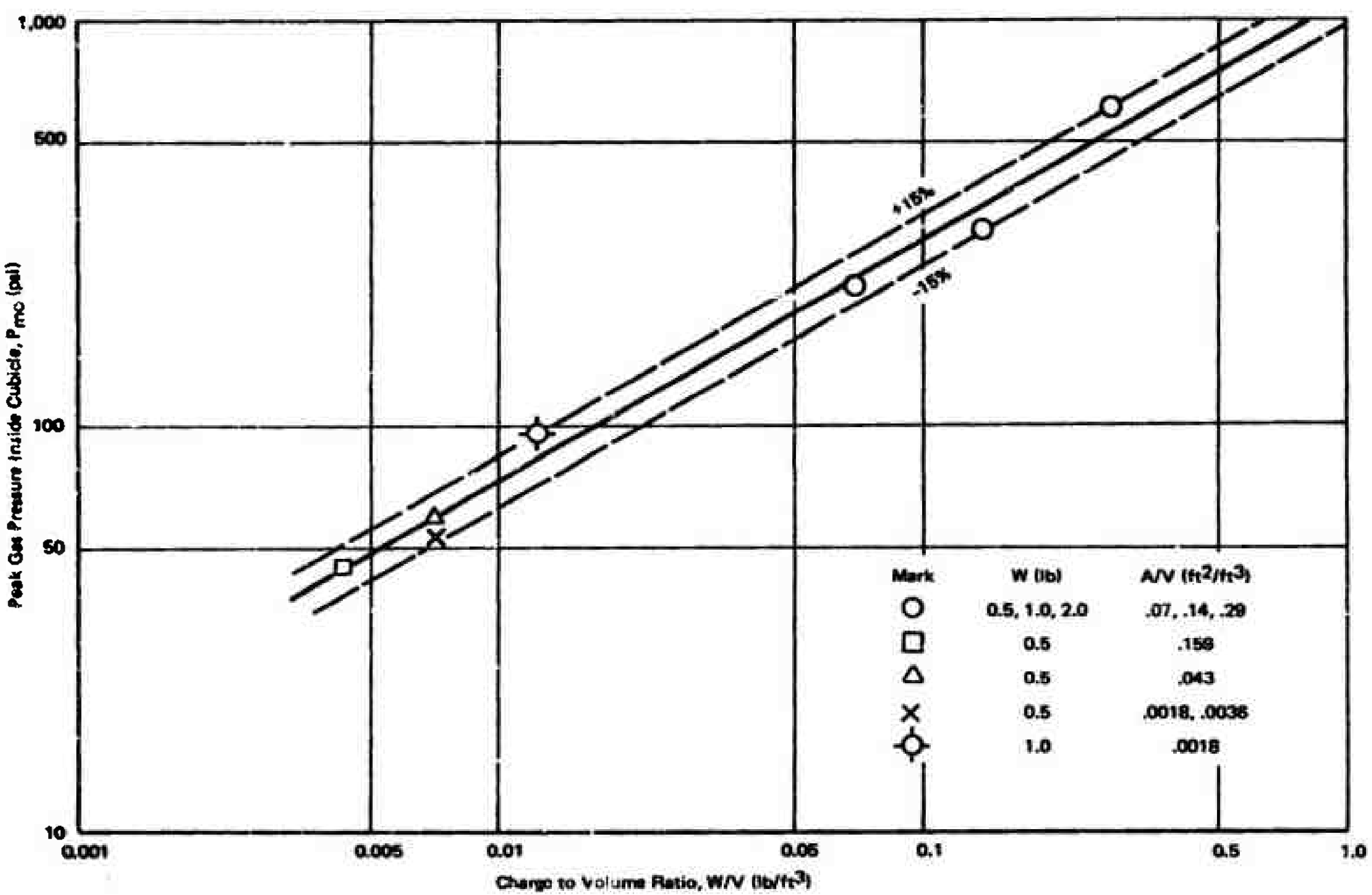


Figure 17. Peak gas pressure inside cubicle versus charge/volume ratio.

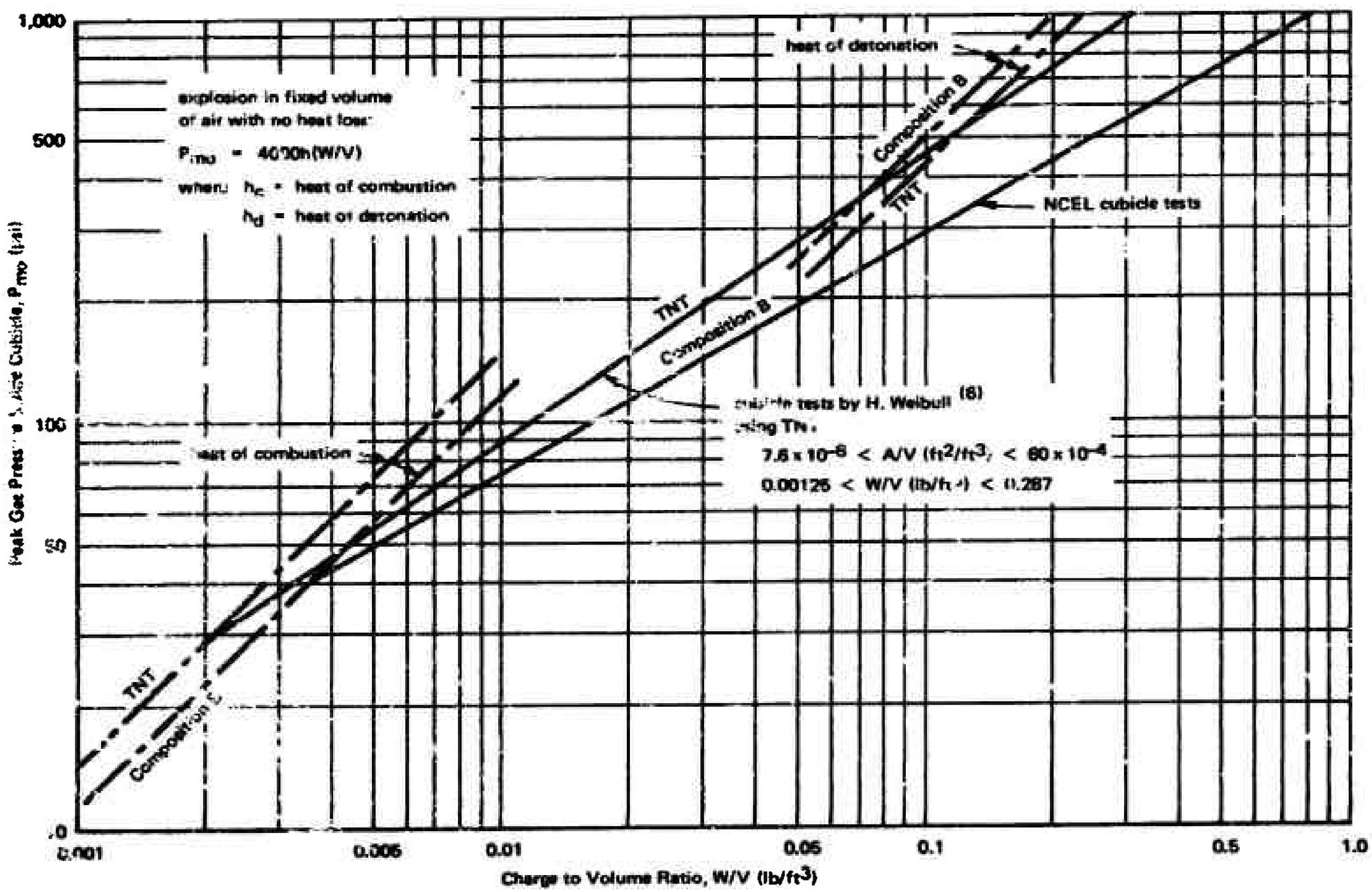
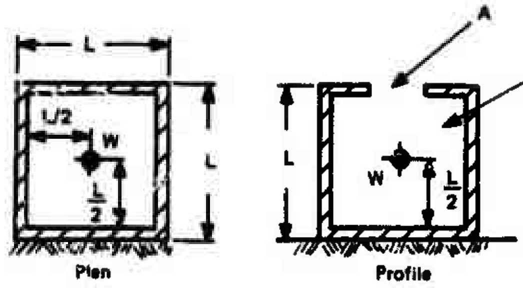


Figure 18. Peak gas pressure inside a cubicle—tests and theory.



Vented Cube

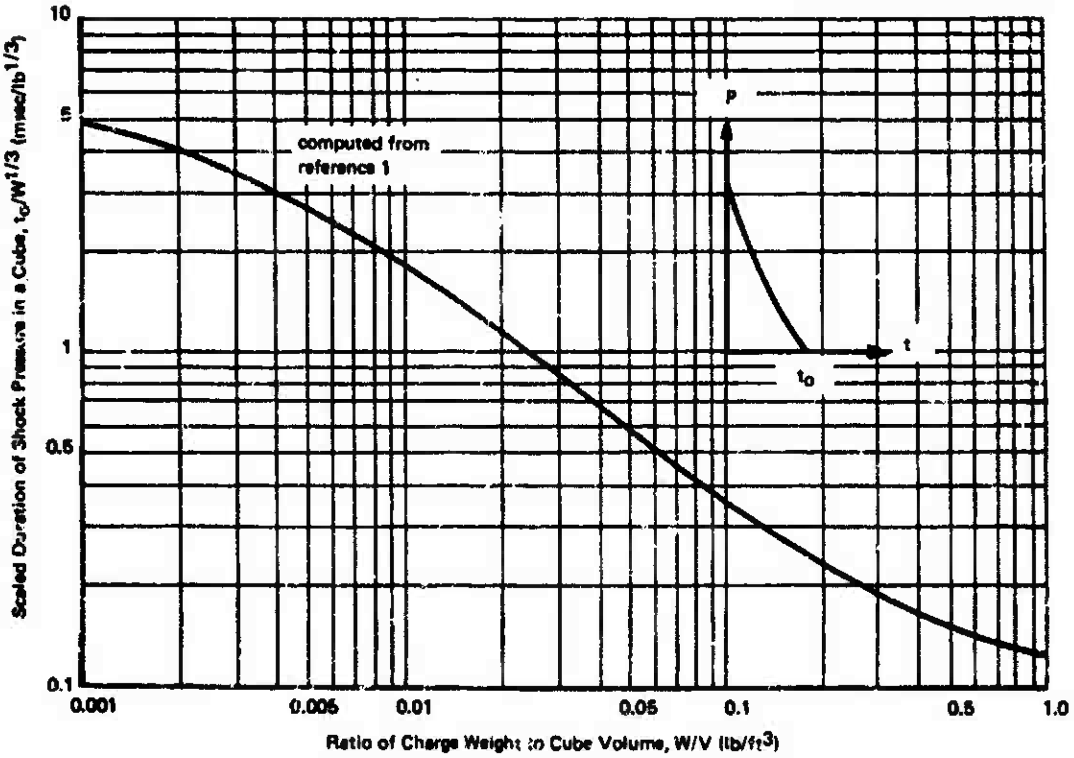


Figure 19. Duration of shock pressure in a vented cube versus charge to volume ratio.

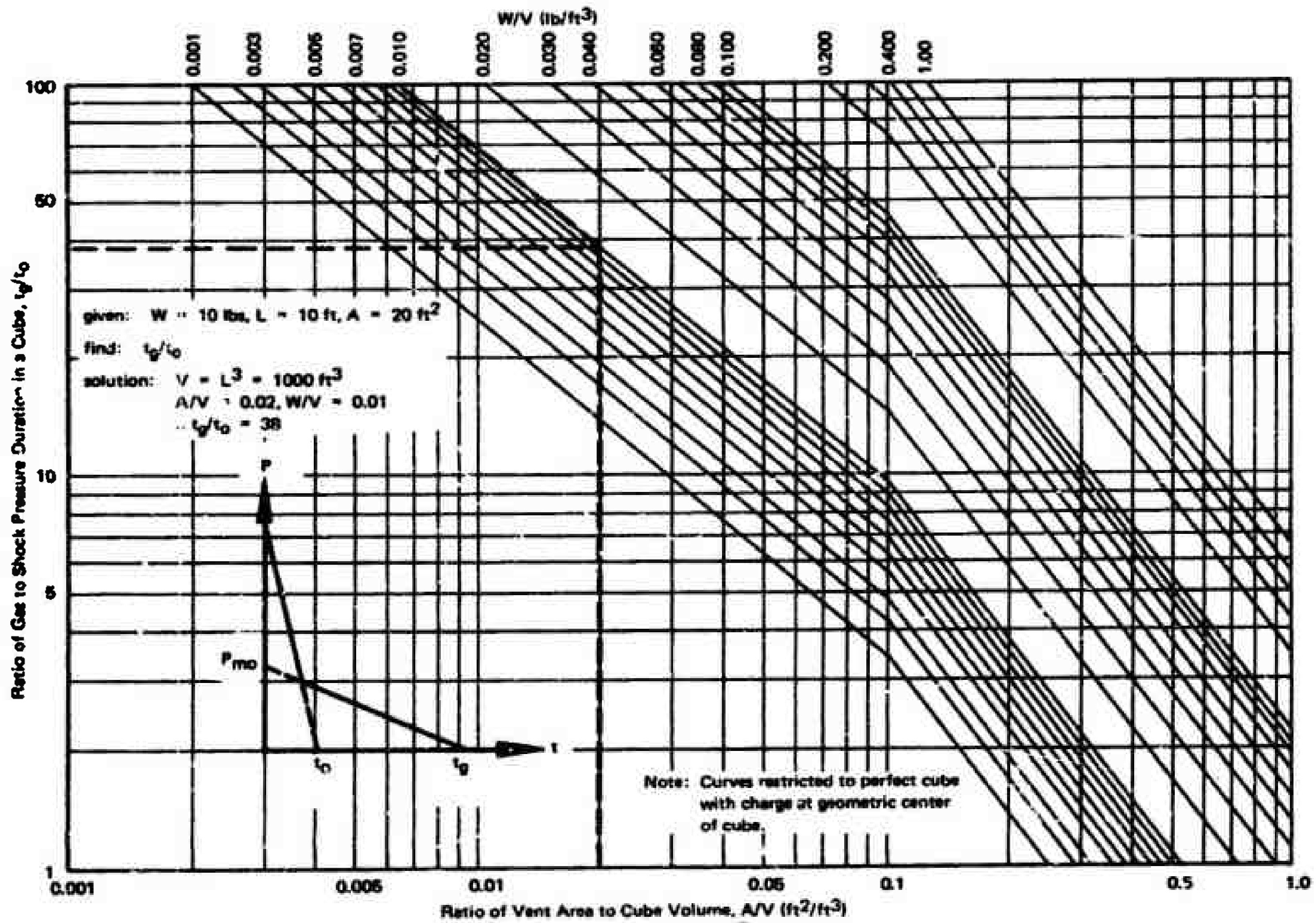


Figure 20. Ratio of gas to shock pressure duration in a cube versus vent area to cube volume.

GROUND SHOCK FROM EXPLODING MUNITION SHIPPING CONTAINERS

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USAEWES, CofEngrs, Vicksburg, Miss.

INTRODUCTION

Background

During June, July, and August 1972, a test series of 10 munitions detonations was conducted. These tests were planned in order to gather information pertaining to accidental explosions of munitions containers and the likelihood of sympathetic detonations of surrounding containers. In particular, these tests examined the problem of shipboard packing configurations.

The tests were conducted under the direction of the Department of Defense Explosive Safety Board (DODESB) with support of the Ammunition Equipment Office, Tooele Army Depot. The Tooele project engineer requested the Weapons Effects Laboratory of the USAE Waterways Experiment Station to provide support in the instrumentation and measurement of the ground shock phenomena associated with such tests.

These tests were intended to simulate certain aspects of munition laden cargo ships. Specifically, standard 8-ft by 8-ft by 20-ft shipping containers (Milvans) were used to house the explosives. The Milvans were loaded with various types of munitions as would be typically found aboard a ship. Several of these Milvans were then placed together in an excavated pit in order to approximate the loaded configuration of a ship's cargo hold. Table 1 lists the several types of munitions used along with the total weight of high explosives contained in each Milvan of this type munition.

Objective

The overall objective of the tests was to resolve certain questions relative to the possible percentage of the total explosive weight of a loaded cargo ship which would contribute to blast overpressure if one or more vans accidentally exploded.

The objectives of the instrumentation projects were to document the blast or explosion characteristics in order to ascertain the sequence and the completeness of the detonations. High speed photography was used to determine the explosion sequence and airblast measurements were used to

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Table 1

Munitions Used

Type	Explosive wt. (per Milvan) (lbs)
Mine, M15 Anti-Tank	9,849
Bomb, 500 lb	21,024
Propellant, Arty.	17,064
Cartridge, 90 mm	5,676
Cartridge, 50 cal.	3,203

determine the shock magnitudes. Sinca the Milvans were placad in open pita, ground ahock waa meaaured to complement tha photographic and airblast measurements.

Approach

For each test, vans were placed as is shown in Figure 1. With the exception of Shot 9, which was used as a control or raference shot all shots used three or more vans. One van was aelected as the detonator van, or donor. Thia van was detonated with a blasting cap with several pounds of Composition B aa a booster. One or more vans (buffer vans) wera used to mitigare the shock or buffer the remaining vana. The final van in the array was the acceptor van used to verify if aympathetic detonation occurred.

Table 2 lista the van configurations used on each shot. The donor used on Shots 1-4 was a aingle van of anti-tank mines, each with a total explosive weight of 9849 lbs of Compoaition B. Shots 5-10 used 500-lb bombs as donora, with a total charga weight of 21,024 lbs of tritonal per van. Shot 7 used two donor vans, armed to detonate aimultaneoualy. Acceptor vans used were loaded with anti-tank mines for Shots 1-5 and 500-lb bombs in Shots 6-10. Buffer vana were loaded with various other munitions as shown on the table.

Operationa

These tests were conducted at the Hill Air Forca Base, Lakeside Test Range, Utah. As listed in Table 2, the ten shota were conducted during June, July, and August 1972. An area was selected and the site prepared during early June. A ganeral view of the sita layout is givan in Figura 2.

In addition to the ground shock project by WES, Tooele Dapot parsonnel conducted the photographic and airblast programs. For the ground shock project, some 24 electronic data channels wera used on aach shot. Figura 3 shows a schematic view of the gaged area. The gages consisted of 18 accelerometers and 6 earth streas gages. Two types of accelerometers wera used; the high range gages (25-2500 g) wera manufactured by the Endavco Corporation and the low range gages (1-5 g) were made by Kistler Instrumenta. The earth stress gages were fabricated in-housa at WES.

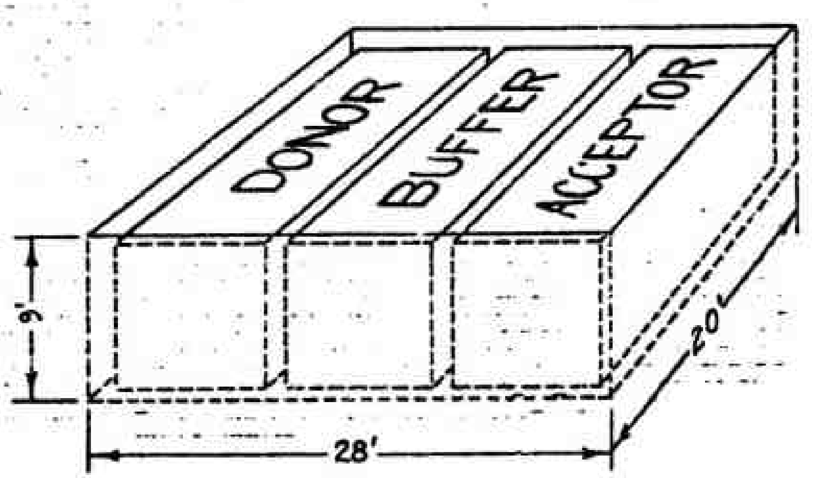


Figure 1. Van Placement

Table 2

Milvan Configurations

Test	Donor Vsn (s)		Buffer Van (s)		Acceptor Vsn (s)		Total Wt.
No.	No.	Munition	No.	Munition	No.	Munition	lbs
1	1	Mines	1	Cartridge, 90 mm	1	Mines	25,374
2	1	Mines	2	Cartridge, 90 mm	1	Mines	31,050
3	1	Mines	2	Propellant, Arty.	1	Mines	53,826
4	1	Mines	1	Cartridge, 50 Cal	1	Mines	22,901
5	1	Bombs	2	Cartridge, 90 mm	1	Mines	42,225
6	1	Bombs	2	Cartridge, 90 mm	1	Bombs	53,400
7	2	Bombs	2	Cartridge, 90 mm	1	Bombs	74,424
8	1	Bombs	1	Cartridge, 90 mm	1	Bombs	47,724
9	1	Bombs	0	—	0	—	21,024
10	1	Bombs	2	Cartridge, 90 mm	1	Bombs	49,110

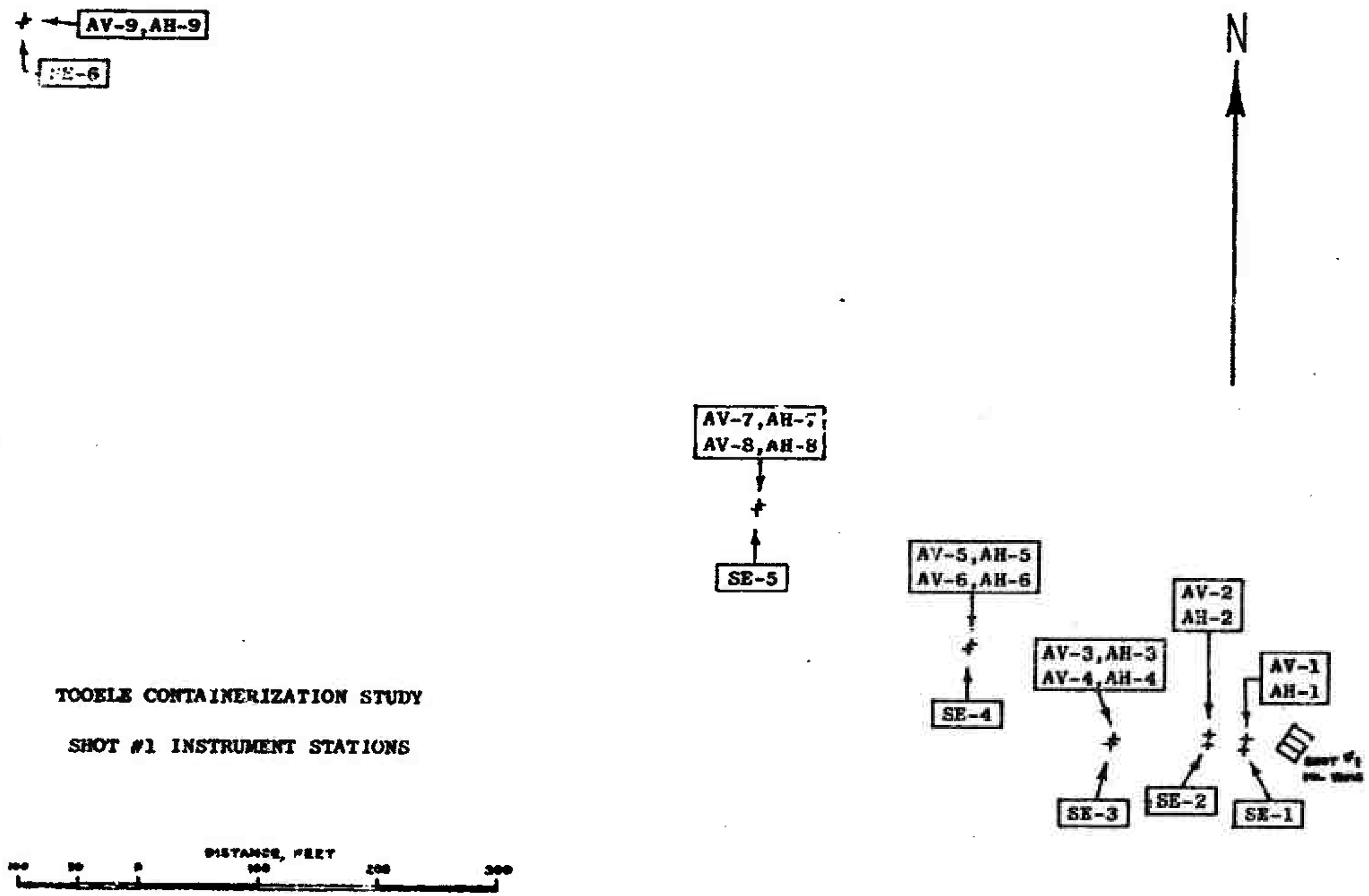
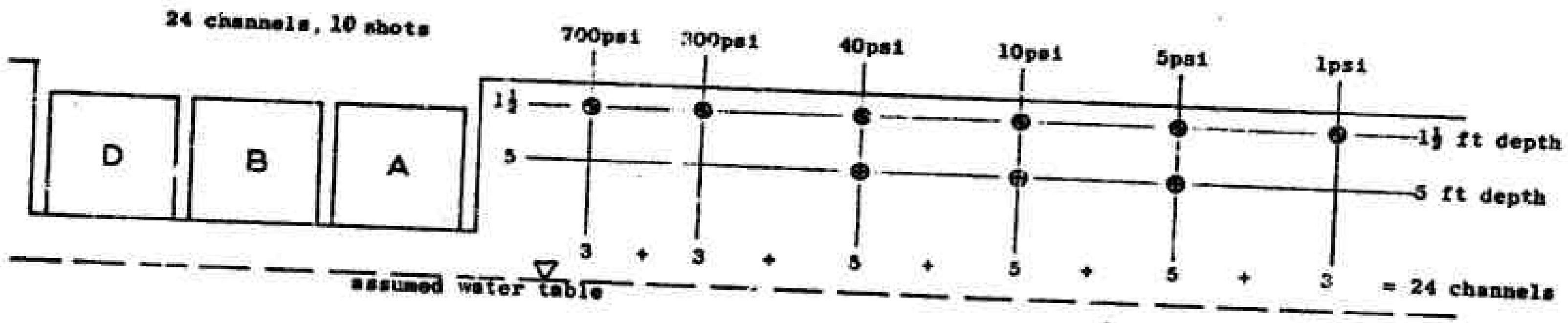


Figure 2. General Layout



KEY TO GAGE STATION SYMBOLS:

- ● 1 radial accelerometer, 1 vertical accelerometer, 1 vertical stress gage.
- ● 1 radial accelerometer, 1 vertical accelerometer.

KEY TO VAN SYMBOLS:

D Donor
B Buffer
A Acceptor

Figure 3. Profile of Gage Array

The gages were used with dc operational amplifiers and were recorded on a Sangamo, Model Sabre III, magnetic tape recorder.

This tape machine has a high density, 32 track recording capability. The data were played back in the field on an oscillograph and the tapes were then sent to the laboratory for processing on A/D and digital computer facilities.

The accelerometers were contained in blast resistant canisters, each canister contained a vertically and horizontally oriented pair of gages. These canisters were then emplaced in boreholes using a soil-cement backfill material. The stress gages were individually backpacked into shallow gage holes.

The individual gage cables were placed in trenches and run back to a common junction box where all were connected through a single multipair telephone trunk cable to the recording equipment, some 3000 ft away. Here the recording van was located under a barricaded shelter, which provided protection from possible flying shrapnel.

<u>Results</u>

Excellent ground shock data were recorded on all 10 shots. Some 240 data channels were recorded. Data reduction and analysis have been completed on the first seven shots of the series. These shots will be used for the following discussion.

Ground shock emanating from explosions occurring near or at the earth's surface is characterized by two distinct pulses. One pulse is given by energy which is coupled directly to the earth by the expanding explosion products; the other is that imparted to the earth by the airblast or air shock as it progresses outward from the explosion source. The latter is sometimes referred to as the "airslap." The two limiting cases, i.e., either a deeply buried burst or a free airburst, produce only directly-coupled shock or airslap-induced shock, respectively. This test would be categorized as a partially-coupled detonation, in that since the vans were in an excavated pit, both directly-coupled and air-coupled energy were imparted to the ground. Figure 4 shows representative wave forms of

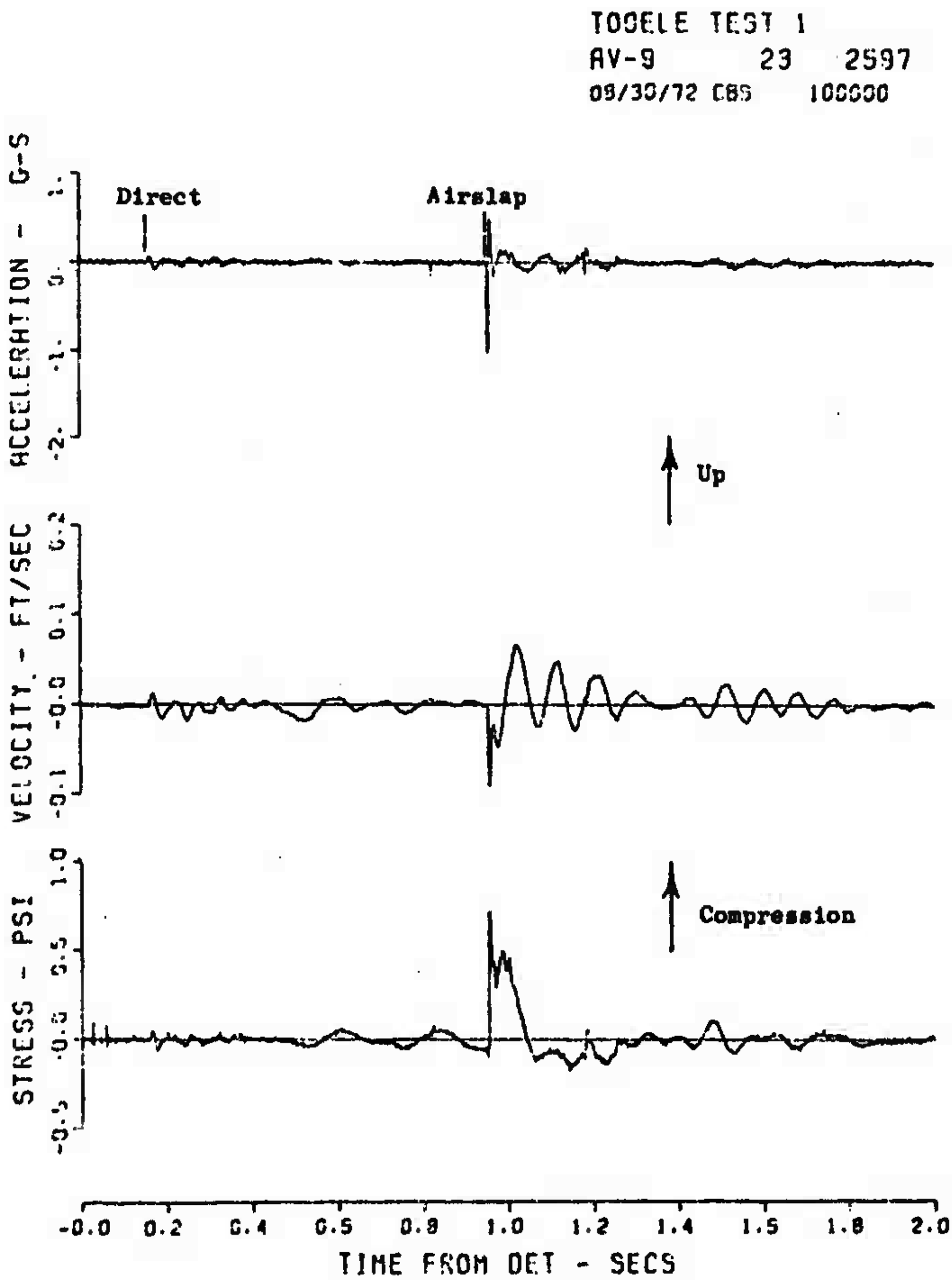


Figure 4. Typical Ground Shock Data

acceleration and stress which demonstrates both the direct- and the airblast-induced pulses. This station is approximately 1250 ft from the ground zero (GZ). The direct pulse arrives at 150 milliseconds (msec) and the airblast pulse at 940 msec. The refracted direct pulse gives an upward thrust while the airslap produces a sharp downward pulse. The stress gage gives a positive output for compression and negative for tension. Both the upward and downward particle motions in this case produce compression.

Figure 5 is a plot of arrival times versus ranges from the center of the charges. The upper earth layer propagation velocity of 1500 fps was determined from an average of Shot 1 and Shot 2, 1-1/2- to 5-ft depth interval velocities, and direct arrival data on the 41-ft range horizontal accelerometer data of Shot 1. A propagation velocity of 1500 fps is typical of clays or alluvial materials. The second earth layer's propagation velocity of 9200 fps was determined from refraction break data from Shots 1 and 2. To judge from the excellent alignment and quality of these refraction data, this lower layer is a sedimentary bed of unusual uniformity at 21-ft depth. Seismic propagation velocities of near 9200 fps are typical of sandstones. Figure 5 also clearly shows that certain of the airblast wavefronts from the various shots arrive at the gaged stations more rapidly than others, a fact which implies a higher order of detonation for the shots having faster airblast arrivals.

An examination of ground motion and earth stress data generated by these tests, indicate that the three far stations (vicinities of 300-, 500-, and 1200-ft ranges) respond elastically to all detonations in the series. The two stations closest to each shot (vicinities of 50- and 80-ft ranges) were clearly in the plastic zone and suffered permanent displacement. These stations were actually in the crater. It appears that elastic earth response to the blast of these detonations begins at a range slightly greater than that of the third station (vicinity of 140-ft range). Though refraction arrivals are quite regular and distinct, and a surface wave is recorded on the motion gages at the two greatest gaged ranges (vicinities of 500- and 1200 ft ranges), the airblast arrival for each shot determines peak responses on earth stress, particle velocity, and acceleration time historics for all gaged ranges.

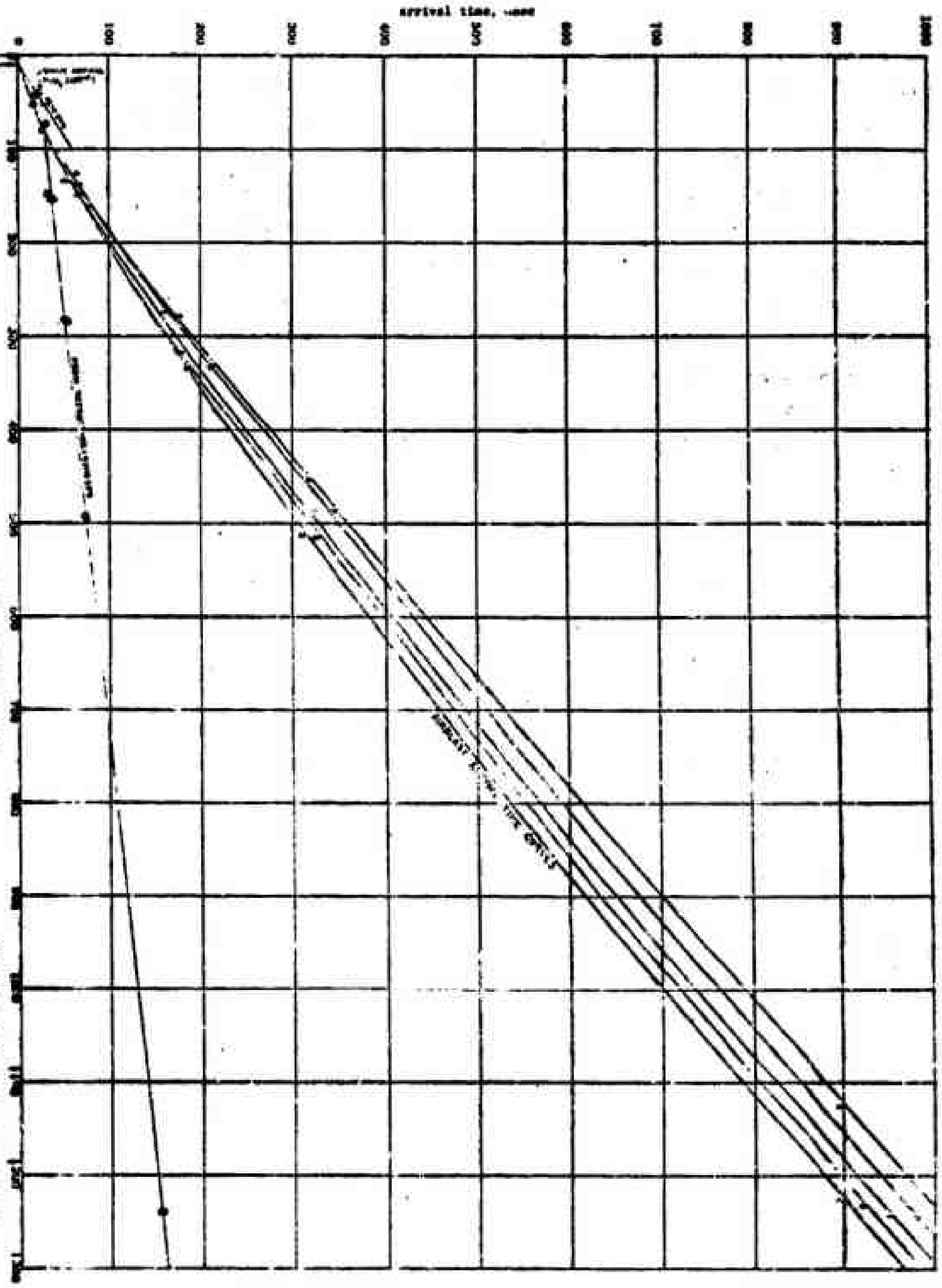


Figure 3. Arrival time versus range.

Figure 6 is a plot of peak airblast-induced vertical accelerations versus range. The shots documented by this figure all had identical donor and acceptor vans; i.e., each had a single van of anti-tank mines as a donor and a single van of anti-tank mines as an acceptor. The buffer van arrangement was changed for each shot. Shot 1 used a single van of 90mm cartridges. Clearly, the use of an additional van load of 90mm cartridges produced an increased buffering effect. Shot 3 substituted two vans of artillery propellant for the 90mm cartridge-loaded vans used in Shot 2. Shot 3 detonation produced higher accelerations than either previous shot, an indication that the artillery propellant is a very poor buffer from the standpoint of safety. (The relatively low values for the two close-in stations on Shot 3 were most likely due to gage rotation during displacement.) Shot 4 used as a buffer a van of .50 caliber cartridges. Evidently this provides the best buffer in the series; the station acceleration levels are somewhat lower than the Shot 2 levels.

The shots documented by Figure 7 all had identical buffers; two vans of 90mm ammunition each. Shot 2 has been replotted from Figure 6 as a reference. Shot 5 differs from Shot 2 in that it has a van load of 500-lb bombs as its donor. Shot 6 replaces the anti-tank mine-loaded donor and acceptor vans of Shot 2 with 500-lb bomb-loaded vans. Shot 7 has two 500-lb bomb-loaded vans as its donor and a single 500-lb bomb-loaded van as its acceptor. Shots 5 through 7 produce the highest ground acceleration levels among the plots of Figure 7. In the case of Shot 5, this high level of ground motion is evidently due to the sensitive nature of the anti-tank mines as an acceptor, whereas, the Shot 7 donor of two van loads of 500-lb bombs evidently produces the most dangerous donor of the series. The 500-lb bombs, however, seem to be less sensitive than anti-tank mines in the role of acceptor.

In summary then, what conclusions can be drawn using the ground shock data as a criterion for evaluating the overall objective? We can rank the explosions in terms of severity of the airblast-induced vertical accelerations. Shot 5 produced the strongest motions. Shots 3 and 1 appear next in order, then 7 and 6, and then 2 and 4.

TOOELE CONTAINERIZATION STUDY - SHOTS #1, #2, #3, #4.

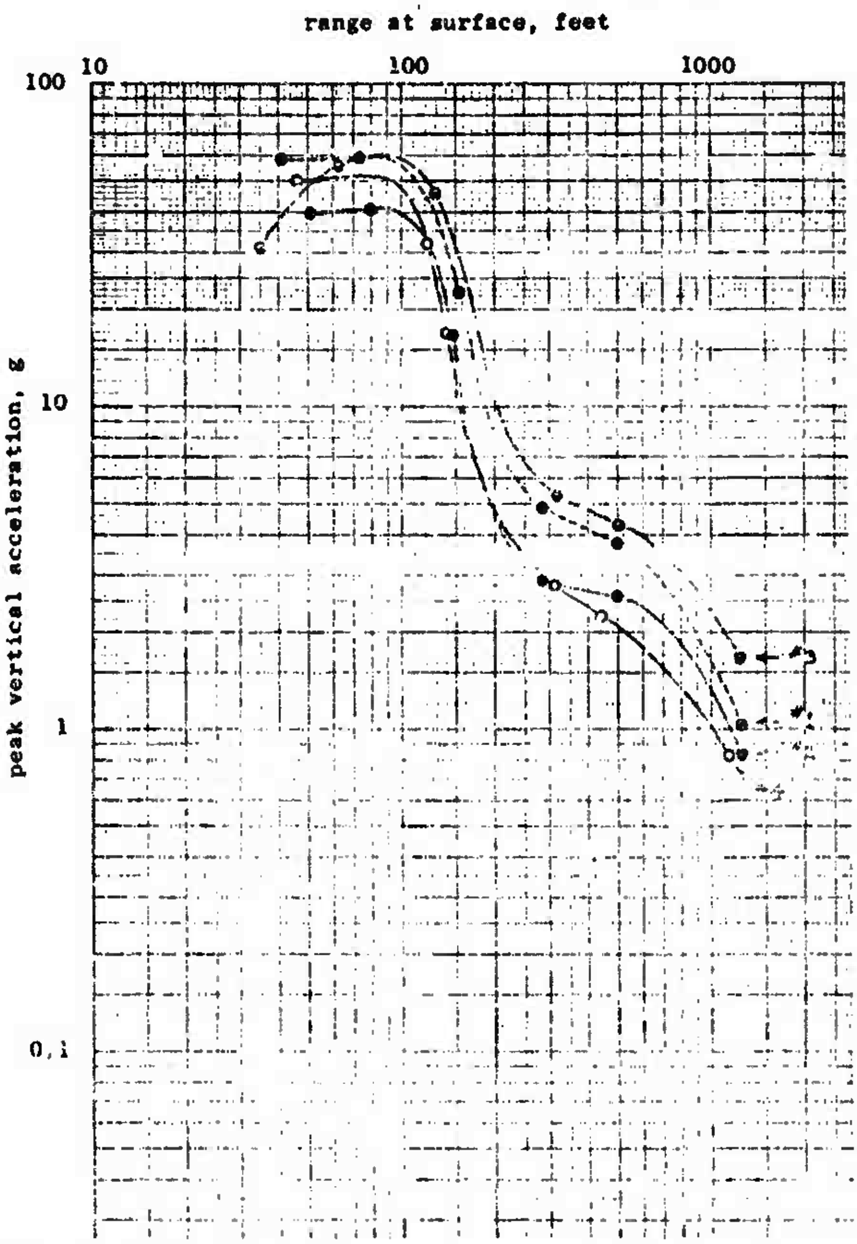


Figure 6. Tests having single vans of anti-tank mines as donar and acceptor.

TOOELE CONTAINERIZATION STUDY - SHOTS #2, #5, #6, #7.

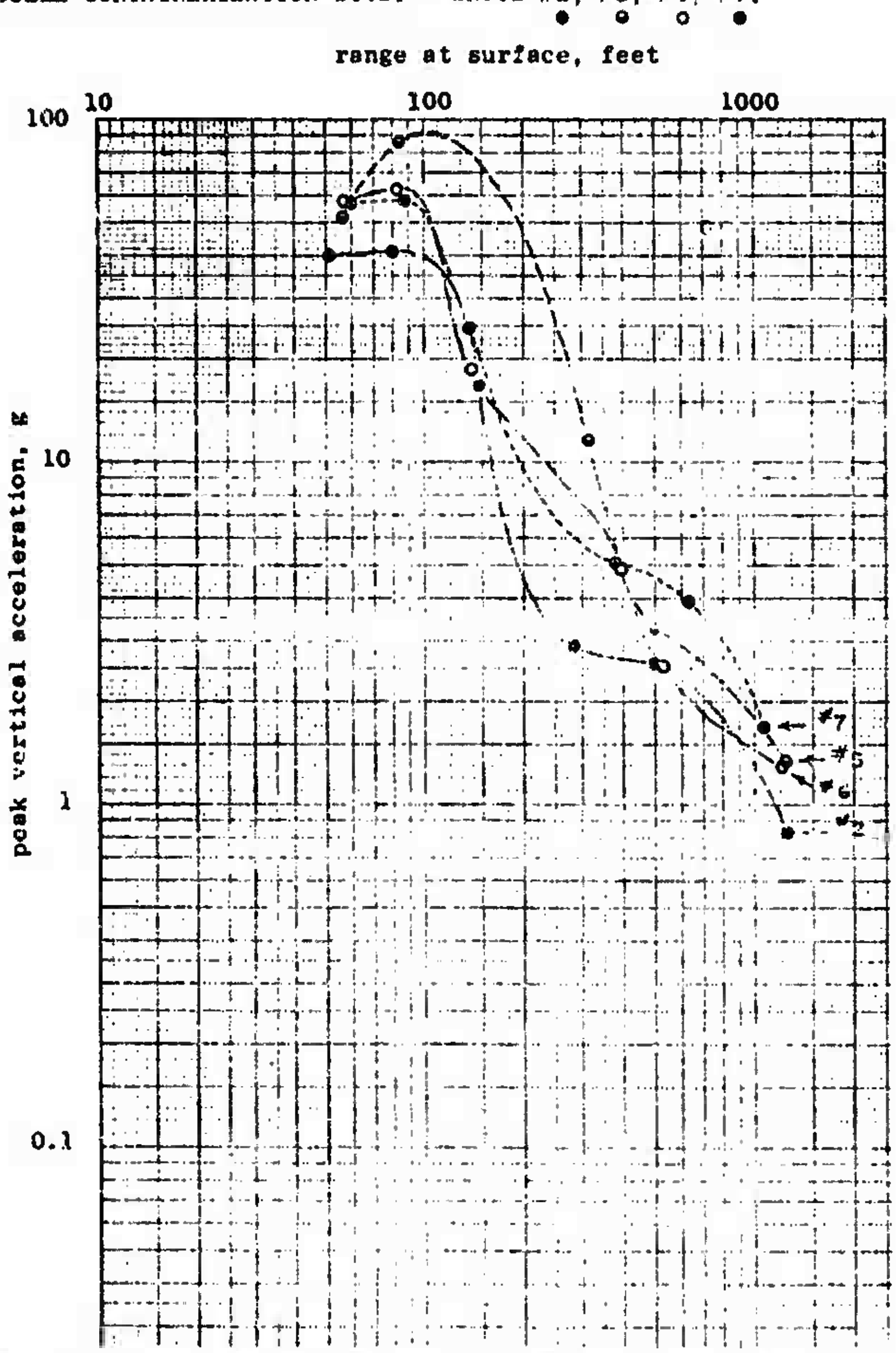


Figure 7. Tests having two vans of 90mm cartridges as buffer.

A look at the post-shot EOD survey of the unexploded munitions, made shortly after each shot, gives an interesting comparison. In particular, comparison of the percentage of acceptor weight and buffer weights exploded will reveal an idea of "success" or severity of the explosion. Table 3 ranks the explosions by these percentages.

Now for a final review, Table 4 compares the ground shock ranking and the EOD survey rankings. This reveals a fairly close agreement.

This table shows Shot 5 with 100 percent of the acceptor and 97 percent of the buffer exploded. Shot 3 had 100 percent of acceptor and 100 percent of buffer to explode. Shot 1 showed about the same. Shots 6 and 7 reveal their acceptors almost entirely unexploded. Shots 2 and 4 had between 2/3 and 4/5 of their acceptors unexploded.

Table 3

EOD Results

Test No.	Total Explosive Weight lbs	Unexploded Weight lbs	Percentage of Unexploded Weight
1	25,374	340	1.8
2	31,050	9,393	30
3	53,826	0	0
4	22,901	6,500	28
5	42,225	340	0.8
6	53,400	17,625	33
7	74,424	28,780	39
8	47,724	7,211	15
9	21,024	880	4
10	49,110	22,030	45

Table 4

Comparison of Results

Ground Shock Ranking	Acceptor Exploded %	Buffer Exploded %
Shot 5 (41985)	100	97
Shot 3 (53826)	100	
Shot 1 (25034)	100	94
Shot 7 (45644)	0	58
Shot 6 (35775)	17	76
Shot 2 (21957)	16	73
Shot 4 (16401)	36	100

DREDGING CANALS WITH EXPLOSIVES

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There are many silt-filled canals in Vietnam which are no longer suitable for navigation and commerce. Opening these canals or constructing new ones would be extremely valuable from a tactical standpoint and would be a boon to the civilian economy.

We have been developing a simple, standardized and cost optimized slurry explosive system for accomplishing the deepening or excavation of these canals. A major objective was to replace the costly Mk 8 line charge which has been used for this purpose. In this paper, a description will be given of the explosive line charges which were prepackaged in the form of ssusages. The evaluations of this system (which is called Explosive Dredge) conducted in the Mississippi Delta and in the Mekong Delta, are described. In the Mississippi geology, a channel 30 ft wide and 6 ft deep was excavated using 45 lb of explosive per linear foot. A canal 20 ft wide and 4 ft deep was excavated using 20 lb of explosive per linear foot in the Mekong Delta geomorphology.

INTRODUCTION

The U.S. Navy has used Mk 8 Mod 3 line charges, which contain 2 pounds of explosive per foot, to excavate silt-filled canals. Explosives excavation methods were selected since conventional dredging techniques such as mechanical dredging or manual labor were ruled out as being unsuitable because they were too expensive and too slow. The stockpile

of these line charges is dwindling and the cost of replacement is considered excessive[1]. A substitute and cheaper explosive system is urgently needed.

To meet this requirement, the Naval Ordnance Laboratory under a project named Explosive Dredge has developed a system using "sausages" of slurry explosive as a suitable Mk 8 line charge substitute.

Preliminary evaluation of this system in the U.S. was conducted in the Mississippi Delta. The final evaluation tests were conducted in the Mekong Delta in Vietnam.

DESCRIPTION AND USE OF EXPLOSIVE DREDGE SAUSAGES

The explosive used in the sausage-like line charges was TOVEX EXTRA[2], a commercial slurry blasting agent produced by DuPont (Ref. (1)). This is a class B explosive, and does not contain any high explosive sensitizers or aluminum. TOVEX EXTRA is an ammonium nitrate based water gel used in the mining industry. It has about a six-month shelf life (Ref. (1)). The gelling agent when exposed to high ambient storage temperatures tends to break down, with the result that the heavy particles do not remain in suspension. The result of this is unreliable detonation performance and reduced sensitivity to initiation. At the end of the shelf life period the explosive can be disposed of by using it as a fertilizer or by dissolving it in water. It should be handled as an explosive.

[1]The last time they were manufactured the cost was $100 per 25 foot length of Mk 8 Mod 3 line charge.

[2]The mention of company and trade names in this paper does not constitute endorsement or criticism by the Naval Ordnance Laboratory.

The bulk density of TOVEX EXTRA is 1.35 grams/cc. To achieve a loading of 10 pounds per foot, the sausage was made five inches in diameter. Reference (1) states that the detonation velocity in a five-inch diameter borehole confinement is 18,000 feet per second. Detonation velocity measurements made during the CONUS Evaluation (water confinement) averaged 12,600 feet per second. Five pound and ten pound per foot sausages were used during the Mississippi Delta tests. The evaluation tests in Vietnam were conducted with ten pound per foot sausages exclusively.

The sausage sleeve consisted of a six-mil polyethylene tube inside a tough Typar polyester tube 10 mils thick. The polyethylene inner lining provided the needed water resistance since TOVEX EXTRA loses its reliability after direct water exposures exceeding one week in duration. The tough Typar outer layer provided reasonably good abrasion resistance.

The explosive was loaded by pumping into the sausage sleeves at the DuPont plant located at Martinsburg, West Virginia. TOVEX EXTRA remains pumpable for a short time after mixing until it cools down from its approximately 100°F blending temperature.

The sausages were all 20 feet long. Both ends of the sausages were clamped-off with a "Tipper Tie". In order to package each two sausages into a 55-gallon drum, the sausages were not completely filled with explosive. This permitted coiling of the sausage into the drum. To avoid the possibility

of detonation failure due to regions that could be starved of explosive, the sausages required some consolidation. This was accomplished after removal from the drums by placing the sausages on an incline and twisting on the upper end of the sleeve. A wire tie was used to prevent the explosive from flowing back into the excess sleeving.

Since TOVEX EXTRA is not cap-sensitive, boosters were required for each 20-ft length of sausage. The boosters used were HDP-1 primers, also manufactured by DuPont (Ref. (2)). They were cylindrical, 2 1/2 inches in diameter, and contained one pound of pentolite. The boosters had axial holes through which primacord for booster initiation could be threaded. The convenience of primacord initiation provided improved safety by eliminating the requirement for inserting detonators into the boosters. Safety fuse initiated, non-electric, detonators were used to initiate the primacord throughout the Vietnam evaluation. A 10-minute fuse permitted sufficient time for the arming party to withdraw to a safe distance. During the U.S. test series, electric detonators were used.

The primary method used for linking the sausages together to form a long line charge was to overlap the ends of the sausages and to tie-in an HDP-1 booster at each lap joint. Because of its good adhering characteristics even when wet, one-inch wide, black, plastic electrical tape was used to form the lap joints. This tape was also used to repair sausages occasionally punctured in the course of excessively rough handling.

THE EVALUATION SITES

The full scale CONUS evaluation program was conducted at the U.S. Army Corps of Engineers, Big Black Test Site located on the Big Black River about 20 miles southeast of the Waterways Experiment Station (WES), Vicksburg, Mississippi. The basin where the tests were conducted was 100 feet wide and 250 feet long. A berm 15 feet high surrounded the basin. This site is in the Mississippi delta region. The soil at the test basin consisted of firm clayey silts and silty clays of low plasticity. This type of material was indicated to a depth of at least 10 feet. At the soil/water interface, there was a layer of very soft mud 1/2-foot deep. Average dry density and water content for the soil down to a depth of 10 feet was 97.7 pounds per cubic foot and 28.1% respectively (Ref. (3)). The water depth in the basin was varied from 0 to 4 feet.

The Vietnam canal site was three kilometers north northwest of the post headquarters at the Dong Tam, RVN, Naval Base. Since May 1970, a mechanical dredge operated by Vietnamese civilians had been working to excavate a new canal across the rice paddies in an eastward direction perpendicular to the Kinh Xang Canal. The progress of the mechanical dredge was very slow, advancing less than a kilometer in six months. The purpose of the constructed canal was to form a link between the Kinh Xang Canal and the Rach Thay Khan Stream. Figure 1 shows the location of the canal and its proximity to the base at Dong Tam.

During the course of the Vietnam evaluation, it was not possible to arrange for a soil test at the canal site. However, a soil log which was obtained in 1969 during construction of the base at Dong Tam, revealed an interesting feature of the near surface geology of the immediate area. Beneath a layer of inorganic silty clay of medium plasticity about 10 feet thick, there was a region of high plasticity clay of low density and high water content. In this region, the soil boring tool only required pushing, whereas, in the upper region about five blows per foot were required to advance the tool. In addition, the compressive strength which was about 700 psf in the upper region dropped to 200 psf in the extremely soft region. The effect of this geological condition on explosive dredging is discussed later in this paper. The water depth averaged less than one foot.

MISSISSIPPI DELTA TESTS

The tests in the Mississippi Delta were designed to generate basic cratering data which could be used to specify the explosive charge configuration needed to excavate channels about 30 feet wide and 6 feet deep. Initially, tests were conducted using single lengths of sausage in about 2 feet of water. The weight of explosive per linear foot was varied between 5 and 15 pounds per foot and the "apparent crater" profiles were measured. Figure 2 contains plots of the crater profiles for 5, 10, and 15 pound per foot sausages fired in the bottom in about 2 feet of water. To study the effect of water depth on cratering, 10 pound per foot sausages were detonated on the bottom in 0, 2, and 4 feet of water. The resultant craters were measured

and their profiles are plotted in Figure 3.

Based on these results it was apparent that, at least in the Mississippi Delta geology, the 30 foot width and 6 foot depth could not be achieved with one firing of single strength sausage.

It was found necessary to use a parallel spaced charge configuration as well as secondary blasting to explosively excavate a channel of the required dimensions. A parallel spaced charge is one where the sausages are placed in parallel on the bottom with a fixed spacing between them. The sausages are then detonated simultaneously from one end. Secondary blasting is the terminology used for a scheme where explosives are detonated in a previously blasted crater to form a deeper and wider final crater. Figure 4 illustrates this method of explosive dredging. The primary crater was formed by sausages 4 feet apart. The secondary and final crater was excavated by Explosive Dredge sausages on a 6 foot spacing. This channel satisfied our design goal. It was at least 30 feet wide and 6 feet deep and was formed by a total explosive loading of 45 pounds per linear foot.

During these tests, airblast and underwater pressures were measured. Based on the measurements, safe stand-off distances for personnel from the end or along the parallel side of the charge should be 500 feet for firings as large as 1,000 pounds. For greater weights, a proportionately greater distance should be considered for safety. The stand-off distances for unloading water craft should be that for its personnel aboard. Boat

damage from underwater shock is unlikely.

EXPLOSIVE DREDGE MEKONG DELTA EVALUATION

The site selected for the Vietnam evaluation was typical Mekong Delta rice paddy terrain. The average water depth was less than one foot, and varied between 9 and 24 inches. Thus in many cases, there were just a few inches of water confinement (tamping) above the sausages.

To establish the data base for comparison with the cratering performance of the Explosive Dredge sausages, ten Mk 8 Mod 3 line charges were assembled to form a 50 foot long charge with 10 pounds of explosive per linear foot. This charge was detonated on the bottom in water 24 inches deep. The crater formed was about 25 feet wide and 4-5 feet deep.

Three lengths of Explosive Dredge sausage were then assembled end-to-end to form a 60 foot long line charge weighing 600 pounds. The water was an average of 17 inches deep. The crater produced was 20 feet wide and 4-5 feet deep. Figure 5 shows a plot of the crater profile for this test.

Since the single strength sausage produced a much wider crater than at the CONUS test site (20 feet compared with about 12 feet), test firings were designed to establish the optimum spacing* between line charges for the Mekong Delta geomorphology. The test configuration for these shots is shown in Figure 6. The single strength sausage was fired since we were proceeding with the explosive dredging operation where there were only

*Optimum spacing is defined as the largest spacing between parallel line charges where no central ridge is formed in the crater.

about nine inches of water in the rice paddies. This water depth would be more typical of the tamping conditions for the rest of the construction effort. Nine inches of water only provides about four inches of water above the Explosive Dredge sausages placed on the bottom. This degree of tamping provides very little confinement for the explosion product gases which vent very early and certainly dump a large proportion of the blast energy into the air rather than into useful cratering action. The single strength sausage produced a crater 15-20 feet wide and about four feet deep.

In the region where there was a 15-foot parallel spacing between two line charges, the crater formed was about 40 feet wide. However, in the central region, an island-like ridge about 15 feet wide had been formed where the maximum depth was expected. Similarly, in the region where three parallel sausages spaced 10 feet apart were fired, central islands were formed in a crater 40 to 50 feet wide. The craters were about four feet deep along the outer regions.

Secondary blasts were designed to remove the islands and deepen the craters formed. These shots did not produce the expected results. In fact, a new series of islands was formed, having no specific pattern in their formation. Failure of secondary blasting to achieve canal deepening is now attributed to the fluidity of the bottom material in the Dong Tam vicinity discussed earlier in this paper. However, at this time in the evaluation program, we were not aware of the unusual bottom condition.

The explosive dredging operation was begun at a point in the rice paddies about 300 feet from the region where the mechanical dredge had reached. It was now desirable to connect the two regions together in order to improve the handling of the sausages by making it possible to move them on air mattresses instead of dragging them by hand across the shallow rice paddies.

In light of the formation of islands when a 10 foot spacing was used, three parallel sausage line charges spaced five feet apart and 180 feet long were detonated. The cratered region was about 30 feet wide. Again, numerous islands were formed in the central part of the crater, with some areas about four feet deep outboard of the original position of the outer line charges. Figure 7 is a photograph of a section of the crater illustrating the islands formed as well as some of the massive blocks of tough clay ejected by explosive dredging.

Three parallel line charges each 120 feet long and spaced three feet apart were detonated to dredge the 120 feet remaining between the mechanically and explosively dredged canals. The performance was similar to that using a five foot spacing except for the fact that only a 15-foot width was achieved. This is attributed to the narrower spacing used between the line charges as well as the very shallow water depth at the time this shot was fired.

In an attempt to remove the islands, three parallel lines of sausages were detonated. No spacing was used between the line charges. This provided a line charge with 30 pounds of explosive per linear foot. Once again, islands were left in the region where maximum excavation was expected. In some areas

the crater was widened to 60 feet, but the maximum depth at various points varied between four and five feet. Figure 8 is the plot of a crater profile illustrating the island phenomenon.

After searching for and finding the A&E drawings used in construction of the base at Dong Tam, (Ref. (4)) we became aware of the unusually fluid subterranean condition at the canal site. With this discovery, no further attempts were made to achieve depths greater than four to five feet by explosive dredging.

Forty-eight sausages in a double strength, no spacing, configuration, providing a line charge of 20 pounds of explosive per foot were detonated to continue the dredging evaluation effort. The water depth was about nine inches. This shot extended the canal by about 450 feet, forming a channel about 20 to 30 feet wide and three to four feet deep.

Until this point in the in-country evaluation, the explosives and personnel were brought to the canal site from Dong Tam by boat. Since the explosively dredged canal had been constructed as far as 1,000 feet from the place where the boats could beach, the manpower effort of transporting the sausages became too difficult and time consuming for the personnel on the evaluation team.

For the remaining excavation effort, a Chinook helicopter was used to transport all of the explosives to the canal site. This expedient saved about 30 manhours of difficult labor per day of operation. Six tons of explosive were then used to

extend the canal using Explosive Dredge sausages in tandem (i.e., 20 pounds of explosive per foot, no spacing between line charges). Water tamping was about nine inches and since the sausages were laid on the rice plants there were many places where the sausages protruded above the water surface.

To provide increased water confinement, four lengths of Mk 8 Mod 3 line charges were detonated in order to form a shallow trench in which to subsequently lay Explosive Dredge sausages. The purpose of this trench was to improve the capabilities of explosive dredging with the test sausages. The result of the Mk 8 firing was a crater six to nine feet wide and two to three feet deep. Subsequently, sausages were fired in this trench. Two lengths of sausage in a single strength (10 lbs/ft) configuration and double strength sausage (20 lbs/ft) and 60 feet long were fired. Neither of these shots produced significant deepening although widening to 30 feet and to about 60 feet was accomplished.

CONCLUSIONS

On the basis of the Mississippi and Mekong Delta evaluation tests, it is concluded that:

a. Explosive Dredge sausages are equally effective on a weight basis as Mk 8 Mod 3 line charges in excavating canals.

b. In the Mississippi geomorphology, a channel 30 feet wide and 6 feet deep could be excavated using a parallel spaced line charge configuration and secondary blasting, using 45 pounds of explosive per linear foot of channel.

c. In the Mississippi geomorphology, a channel 30 feet wide and 6 feet deep could be excavated using a parallel spaced line charge configuration and secondary blasting, using 45 pounds of explosive per linear foot of channel.

d. Under the geomorphic environment at the Vietnam canal site, new canals could be routinely excavated which were 20 feet wide and four feet deep using 20 pounds of explosive per linear foot.

e. The Explosive Dredge system is well suited for rapid, inexpensive construction of canals of the dimensions given in subparagraph c above. The low cost (approximately $2.10/ft as opposed to $20/ft for Mk 8 line charges) and high excavation rate (100 meters/day) make the system economically sound.

f. The airblast and underwater pressure measurements indicate that personnel should be withdrawn to 500 feet from the excavation site. Boats should be withdrawn to a distance of at least 500 feet in order to protect personnel aboard. The underwater shock waves are not considered sufficiently strong to cause damage to Naval vessels.

g. The cost of an Explosive Dredge line charge 20 feet long, containing 10 pounds of explosive per foot, plus one booster is $41.80. The previously used Mk 8 Mod 3 line charges which contain 2 pounds of explosive per foot and are 25 feet long cost $100 each the last time they were manufactured. The Explosive Dredge sausages were equally effective as the Mk 8 line charges. Therefore, at an explosive load rate of 45 pounds per linear foot of channel, the use of Explosive Dredge sausages

represents a material savings of over $400,000 per mile of dredged canal! Similarly, at an explosive loading of 20 pounds per linear foot of canal, the savings in material alone could be as much as $180,000 per mile!

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2. HDP Primers, DuPont Data Sheet A-13552, March 1964

3. Miller, L., "Water Shock Wave Reflection Properties of Various Bottom Materials", WES Technical Report 1-704, November 1965

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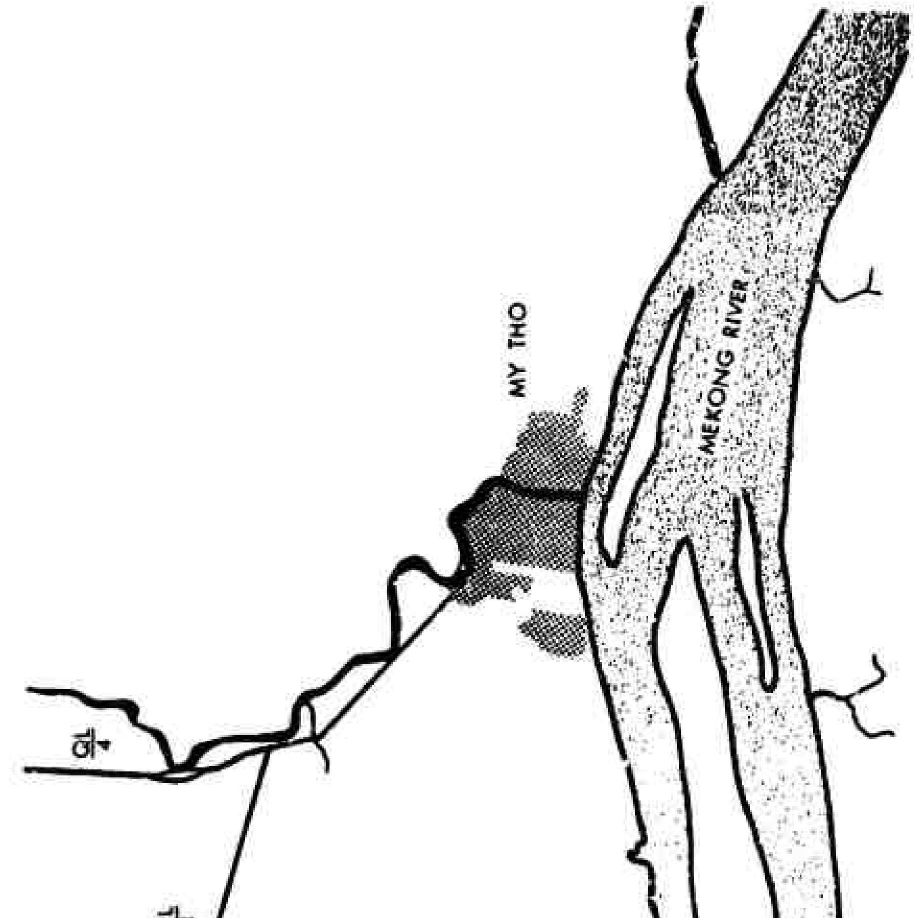

FIG. 1 MAP OF THE DONG TAM REGION SHOWING THE LOCATION OF THE EXPLOSIVE DREDGE CANAL TEST SITE

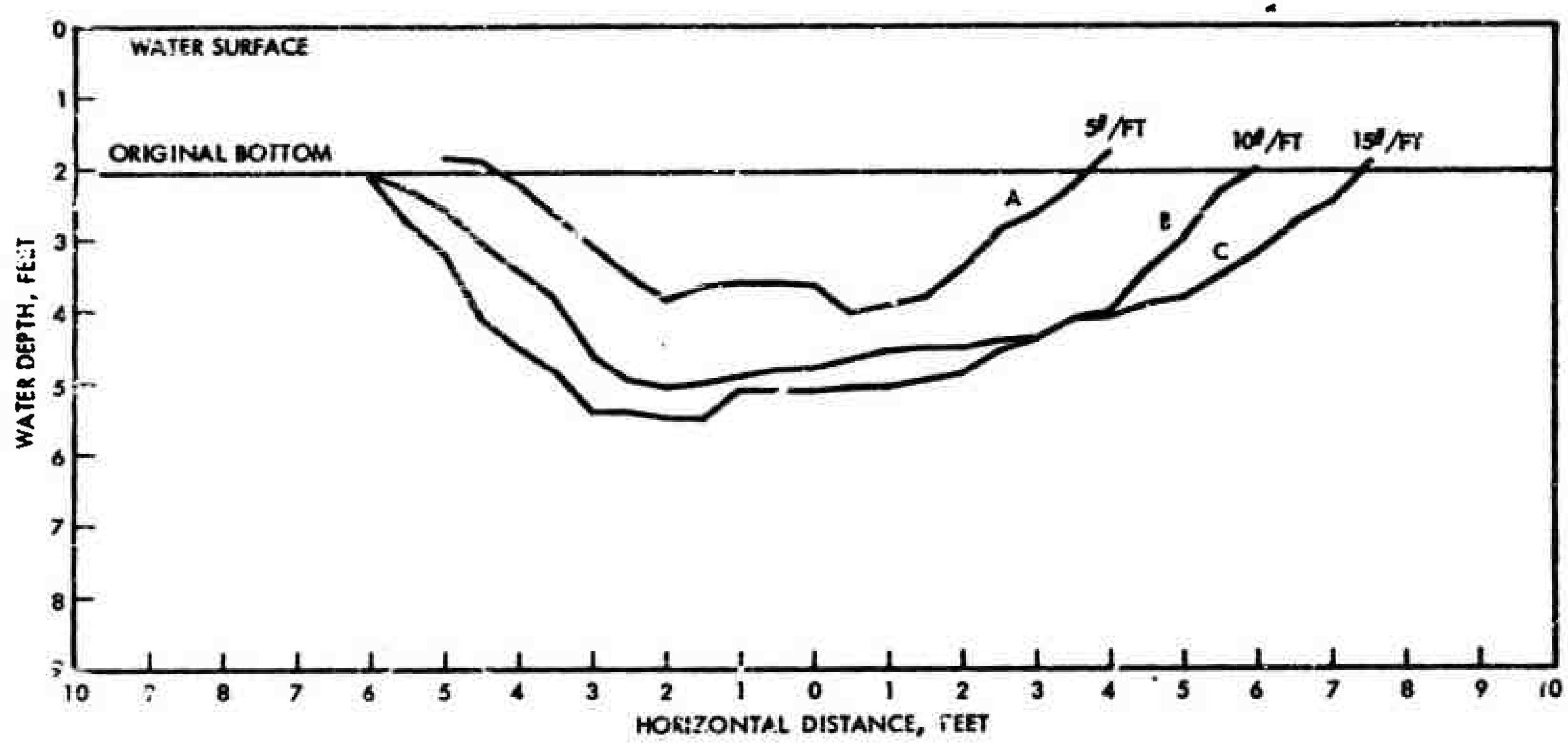

FIG. 2 COMPARISON OF 5, 10, AND 15 POUND PER FOOT CHARGES FIRED IN ABOUT 2 FEET OF WATER; CHARGES 20 FEET LONG

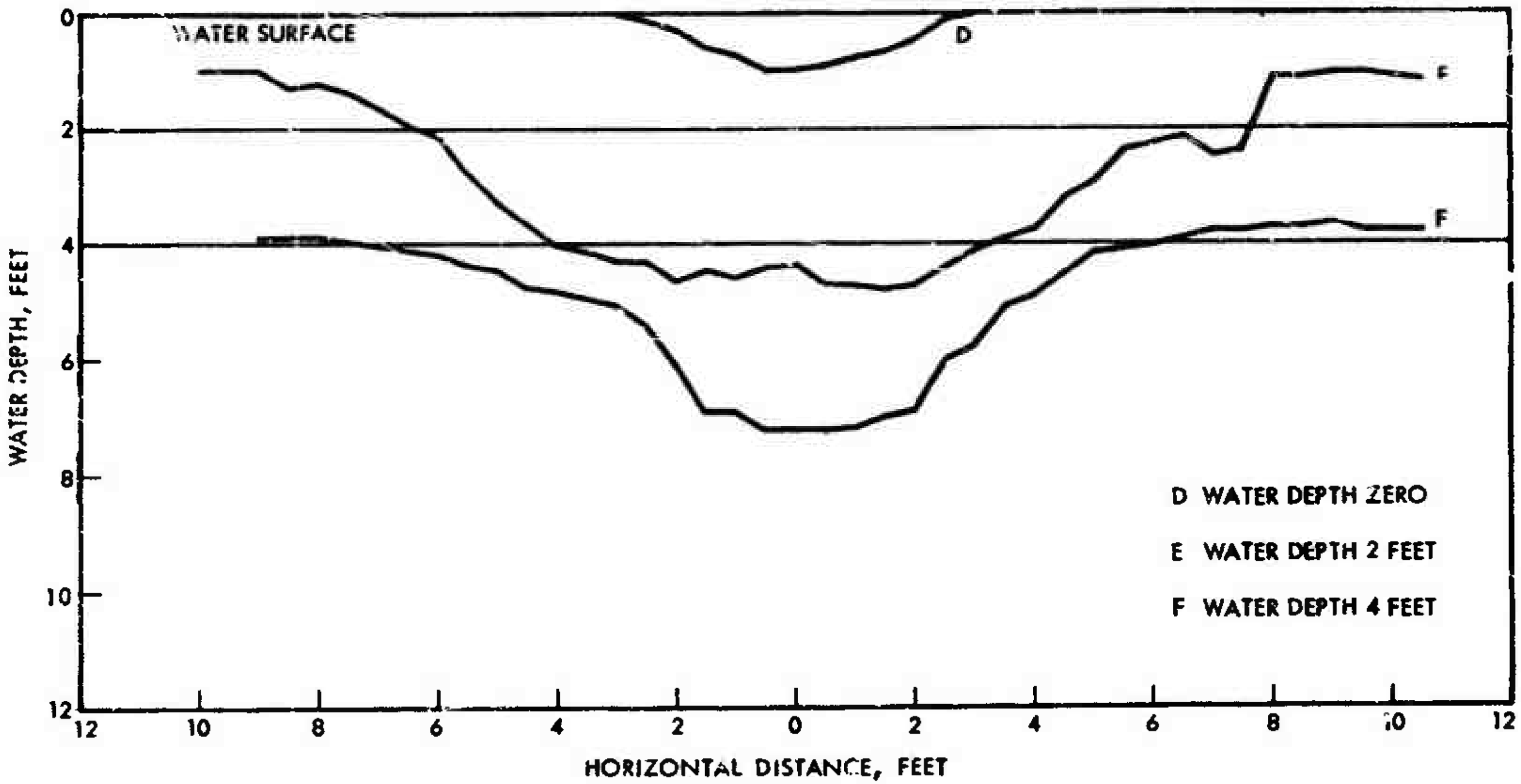

FIG. 3 COMPARISON OF CRATERS FORMED BY 10 POUND PER FOOT SAUSAGES FIRED AT WATER DEPTHS OF 0,2, AND 4 FEET; CHARGES 20 FT. LONG

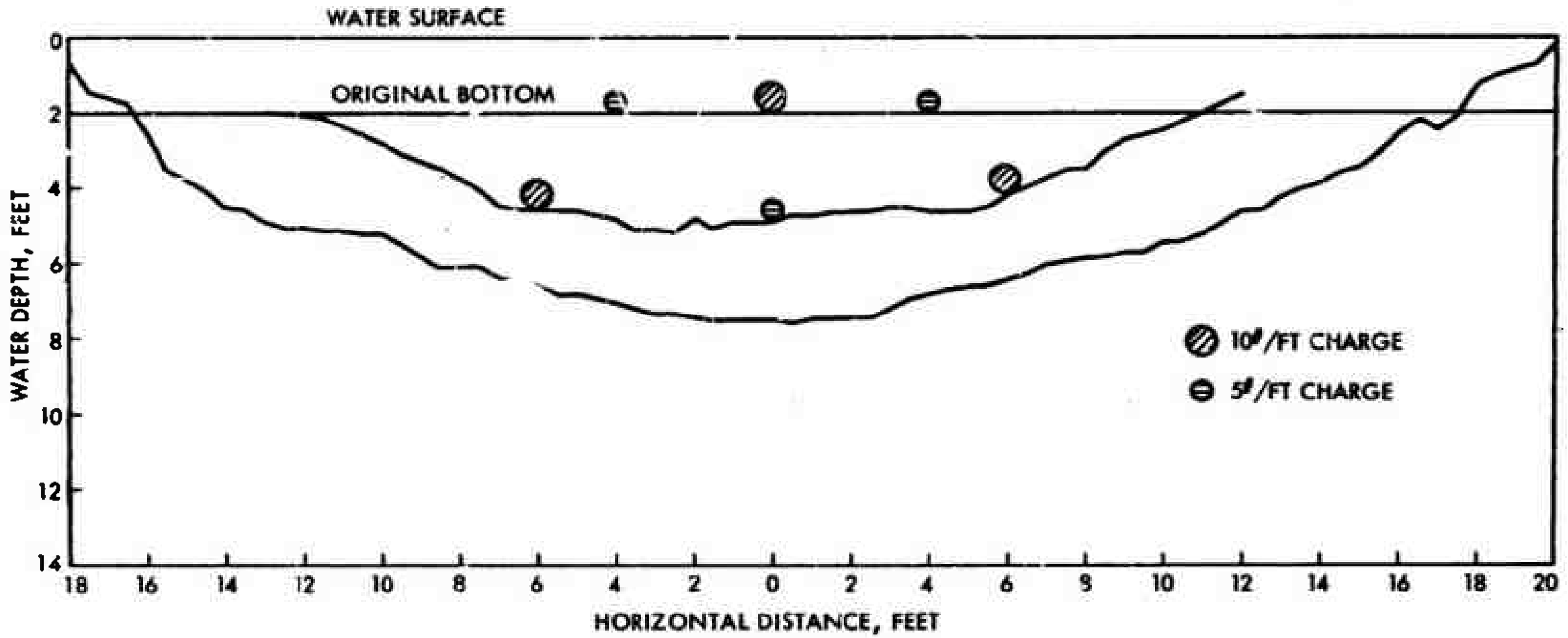

FIG. 4 CRATERING WITH PARALLEL CHARGES AND SECONDARY BLASTING. 3 PARALLEL CHARGES 4 AND 6 FEET APART

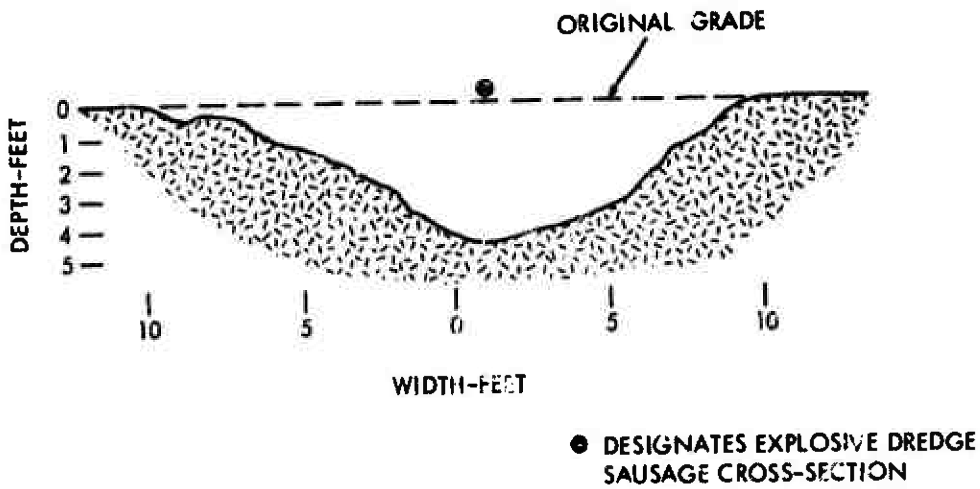

FIG. 5 CROSS-SECTION OF CRATER FORMED BY EXPLOSIVE DREDGE SAUSAGES IN 17 INCHES OF WATER.

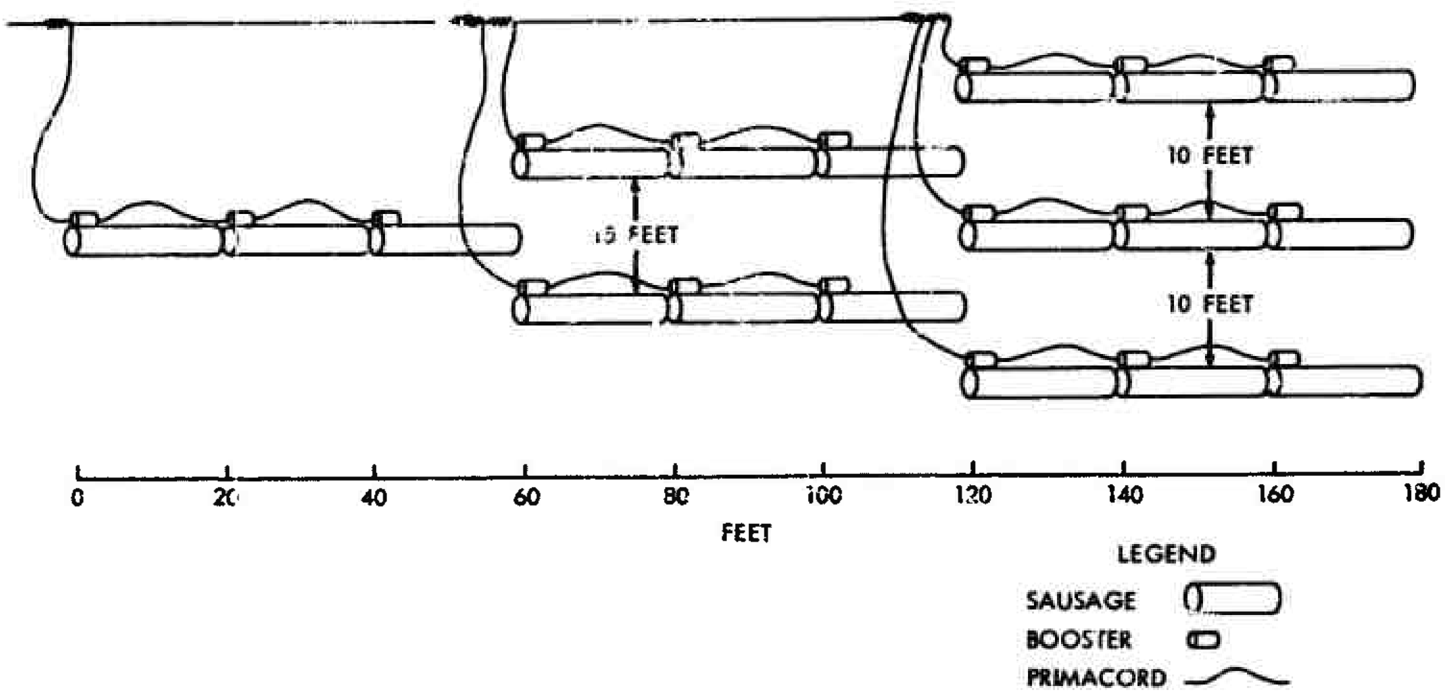

FIG. 6 CHARGE PLACEMENT FOR TESTS TO ESTABLISH OPTIMUM SAUSAGE SPACING AT MEKONG DELTA CANAL SITE.

FIG. 7 PHOTOGRAPH OF THE EXPOSED REGIONS OF A CRATER SHOWING ISLANDS IN THE FOREGROUND AND MASSIVE TOUGH CLAY BLOCKS IN THE BACKGROUND.

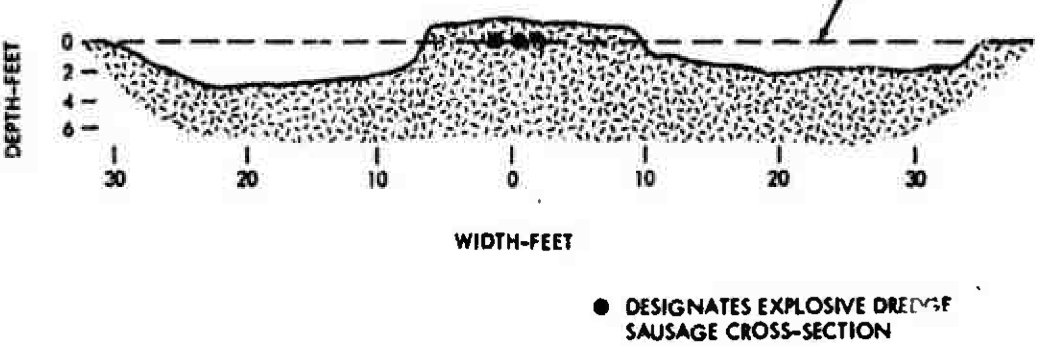

FIG. 8 CROSS-SECTION OF CRATER FORMED BY TRIPLE STRENGTH SAUSAGE.

EXPLOSIVE EXCAVATION - MILITARY APPLICATIONS

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Fall, 1941, in Russia outside Moscow: "Before I left they told me at (Soviet) Army Headquarters: 'Find out whether it is possible to build anti-tank ditches by throwout blasting. We hope you can help, for it is out of the question to dig such defenses by hand.' In Salizharovo (Kalinin District, 200 KM northwest of Moscow) I learned that the (German) enemy was near and had not yet been stopped. There was not a minute to lose. We plotted the line of the ditch, brought up the explosives and started work round the clock, without rest or sleep. The roar of our explosions echoed the gunfire of the approaching front. Nazi aircraft often appeared overhead, bombed and strafed us with machine guns, but nothing could stop our men, who knew the importance of completing their defenses in time--behind us was Moscow. Within a few days we built a ditch 83 kilometers long. It later played a very important role, for it was at this ditch that the Soviet troops halted the Nazi advance on Moscow."[1]

Could the U. S. Army conduct such an operation on a battlefield in the 1970's? Some of you might say: "Yes, we have the Atomic Demolition Munition (ADM) for that." But do we know the effects and effectiveness of the ADM for such applications? What if ADM's can't be used for various reasons? Could we use conventional high explosives?

These are some of the questions the U. S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory (EERL) is trying to answer in a current research program. Explosive excavation is becoming a cost competitive construction technique within the Corps of Engineers on Civil Works Projects.[2] These advances were based on the nuclear excavation technology being developed by the Corps of Engineers and the Atomic Energy Commission since 1962.[3] The current military research is being funded by both the Defense Nuclear Agency and the Military Engineering Directorate of the Office, Chief of Engineers (OCE).

Background

Both nuclear and chemical explosives offer the tactical commander a valuable means of accomplishing his barrier and denial operations through their ability to rapidly create massive obstacles in the face of the enemy. However, the information required to confidently emplace and use these valuable tools is sorely lacking.

For example, cratering data permits us to predict crater dimensions only to within ±50% for most geologic structures; an accuracy which is unacceptable if we are to place any reliance on ADM in barrier plans. Furthermore, there are various questions as to which effect controls troop safety when low-yield, buried ADM are used. Unclassified data predict a troop safety distance for a hypothetical 0.1 KT buried munition of 590 meters

for warned, protected personnel. Yet the radius of the base surge may be 600 meters and maximum missile throwout may extend to 800 meters. The controlling effect must be determined since it will affect the ability of the tactical commander to adequately cover the crater obstacle with direct fire. In addition, data on target destruction (such as dams, bridges and tunnels) are considered to be appreciably more conservative than necessary.

Conventional high explosives offer the commander a non-nuclear alternative to ADM for barriers, target destruction, and construction. However, neither the equipment, the explosives, nor the technology for use of bulk commercial explosives are in the hands of Army Engineers so that they can be properly utilized. Present techniques rely on out-dated Ammonium-Nitrate cratering cannisters. In order to emerge from the dark ages in our use of explosive excavation for barriers and construction, the technology must be developed for the military application of the many new efficient explosives available. Variables which must be investigated include: the size and shape of the emplacement hole; maximum volume of explosive, proper boosting techniques; the effect of various types of terrain and geology on emplacement design; and the design of specific barriers and construction projects, row craters such as defile closures, airfield and dam destruction, road cuts and shelter emplacements.

EXPERIENCE FROM CIVIL WORKS PROJECTS

Cratering Phenomena

The term "explosive excavation" is a general term which denotes the use of explosive charges to produce an excavation by fracturing the material and casting it into a desired configuration. The effects vary with the depth of burial (DOB) from a shallow crater (for a surface burst) to a mound (when the charge is buried deeply). Optimum depth is that DOB where the greatest amount of material is ejected from the crater.

In its simplest form, this technology involves detonation of a single explosive charge buried at the proper depth to produce a crater which is roughly hyperbolic in cross section. In its most complex form it involves such things as directed blasting where material is cast into a desired position, and structural excavation with large charges where material is broken in place and fracturing beyond the excavation boundary is minimized by controlled blasting techniques (see Fig. 1). The terms "quarrying" and "mounding" as used herein describe variations of the technology in which large concentrated charges are used to fracture material in place but without the stringent requirement for control of the extent of the fracturing as in structurel excavation.

Cratering and directed blasting are alternate methods to conventional blasting and hauling of soil and rock on construction jobs. Similarly, explosive quarrying, mounding, and the use of large charges in structural excavation are alternatives to the conventional rock blasting operations conducted as a necessary part of many construction projects. The use of large concentrated charges offers substantial potential benefits when excavation is a major project activity. The principal potential advantages are speed of construction, economy, and, on some projects, environmental benefits.

Explosive Excavation Design

In many applications it is necessary to use an array of several charges to produce a crater of suitable geometry. The simplest and most common array is a row of charges. The charges, usually five or more in number, are buried along the alinement of the desired crater with a horizontal spacing approximately equal to the crater radius for a single charge having the weight of one row-charge member. A properly designed row of charges will excavate a trench having a smooth and uniform cross section even though the charges are separated by some distance. Furthermore, the excavated volume per ton of explosive in the row is greater than for a single charge in the same material. More complicated designs employing multiple rows and sequential delays between both charges and rows are often necessary to achieve specific project requirements at minimum cost or to limit undesirable effects.

Beneficial Aspects of Explosive Excavation

The principal advantages of explosive excavation (dollar savings, speed of construction, and environmental benefits) have varying influence on any specific project. The present cost status is discussed below, and its advantage is quite obvious. Not only ie speed of construction an advantage in some cases where weather, project necessity, etc., are critical factors, but the reduction in heavy earthmoving or dredging equipment requirements could

also be significant. In a channel-widening project recently considered, the environmental advantages of blasting only once rather than drilling and blasting over a long period followed by dredging, were deemed very significant by the Fish and Wildlife Department, since the single blast would minimize the disruption to the fish runs in the channel. In some cases, explosive excavation offers a much safer and simpler approach as was the case in a project at Drum Inlet, North Carolina, where a plug connecting a dredged channel and the ocean was explosively excavated.

Explosive excavation is on a downward cost trend, and although just competitive at this time on some projects many advances are still possible. A comparison of conventional and explosive excavation cost trends is shown in Fig. 2.

Collateral Effects of Explosive Excavation

The environmental factors of ground shock, airblast, and ejecta must always be evaluated when explosive excavation is used. To this list must be added radioactivity if the energy source is nuclear. Relatively accurate prediction techniques have now been developed for these effects. Ground shock and airblast can be reduced to relatively insignificant levels by sequential detonation of charges and rows. It has been found that a delay in the millisecond range between charges in a row has little effect on crater dimensions but reduces ground shock and airblast effects to those of the largest single charge within the row.

The mass of the ejecta from a cratering detonation is deposited up to several hundred feet from the cut. On some projects, this throwout could be objectionable. If so, the mounding concept or a compromise between cratering and mounding may be desirable. On a sidehill detonation almost all ejecta are deposited downhill.

Fish kill and ejecta distribution in an underwater detonation were originally considered as limiting factors. However, experience has proven that these effects are not serious. Although ejecta are spread over the marine bottom several hundred feet from a detonation, this disturbance is no greater than that caused by conventional equipment. Fish kill is also limited to several hundred feet from the cratering detonation. On Project TUGBOAT, where 40 tons were detonated at one time, fish kill in prepositioned cages was limited to 300 feet from the shot point.

Channel Demonstration

The primary objective of a reservoir connection experiment was the development of a chemical explosive excavation capability. An aluminized ammonium nitrate slurry (blasting agent) was used for the first time in a major row-cratering experiment. Such a slurry with 10 to 20% aluminum is approximately 1.5 times as effective in terms of material ejected as TNT, ammonium nitrate with fuel oil (ANFO), or nitromethane. Although the cylindrically shaped charge had a length-to-diameter ratio of 1, it has since been determined that this ratio can be increased to at least 6 without a significant reduction in cratering efficiency. As the ratio is increased, the drill hole diameter decreases as does the emplacement costs.

A total of 70 tons of the slurry explosive was used to connect a previously detonated row to the Fort Peck reservoir, with the largest charge containing 35 tons. The resultant channel (shown in Fig. 3) is approximately 1370 feet long and 150 feet wide at water level, and has an average depth of 26 feet along the centerline.

The experiment demonstrated that the design of a single row of cratering charges to produce a water conveyance channel is relatively simple and offers cost advantages.

Harbor Project

The use of explosive excavation in April 1970 to produce an entrance channel and berthing basin for a small boat harbor at Kawaihae Bay, Hawaii, marked the first use of this technique in connection with a Civil Works project of the Corps of Engineers. Because no experience was available for underwater cratering in coral, a test series of four 1-ton charges and one 10-ton charge were detonated singly in November 1969. The craters produced by these calibration tests were unique. Instead of a conventionally shaped crater with lips, a wide saucer-shaped crater with no lips was obtained. This was due to the consolidation and crushing of the weak porous coral, the interaction of the water with the ejecta, and the washing action as the water and ejecta refilled the crater. This wide, shallow configuration allowed a less expensive design than one predicted on typical dry crater shapes which had a great deal of overdepth.

The final design for this project, called Project TUGBOAT, is discussed in Ref. (4). The design entrance channel has a minimum width of 130 feet. The berthing basin is 300 feet square at the design depth of at least 12 feet below mean lower low water. Twelve 10-ton charges buried at an average depth of 35 feet below the coral bottom were used. Eight of these charges were used for the entrance channel and four for the berthing basin. The above required dimensions were met or exceeded in all areas by explosive excavation.

Railroad Cuts

Because many Corps of Engineers Civil Works projects require highway or railroad relocations, a project of this type was desired to prove the applicability of explosively excavated road cuts. The requirement to relocate a railroad at the site of the Albuquerque Engineer District's Trinidad dam and lake project on the Purgatorie River near Trinidad, Colorado, provided such an opportunity. The on-site material was weak interbedded sandstone and shale with 5 to 10 feet of overburden. Extensive explosive excavation investigations were undertaken including a comparison of full-charge-diameter drilling, underreaming, and hole-springing as emplacement methods; a comparison of ANFO and slurry explosives; an investigation of the effects of different charge spacing in a row; a determination of the effect on cratering efficiency of sequential detonations of charges in a row (to reduce ground shock and airblast); and evaluation of single and multiple rows detonated on a sidehill; and a comparison of simultaneously and sequentially detonated double rows.

One of the three explosively excavated railroad cuts was made with a directed cratering concept as depicted in Fig. 4. The cut was 500 feet long with a minimum depth of 70 feet. The downhill row of charges was detonated

first lifting the material into the air, followed by detonation of the uphill rows some milliseconds later. The concept was extremely successful and achieved the desired objectives. An aerial view of the cut after detonation is shown in Fig. 5 and after dressing with conventional equipment in Fig. 6.

MILITARY RESEARCH

The artist's concept of Figure 7 illustrates some of the potential applications of explosive excavation in the theater of operations. To develop this potential, an extensive research project is being carried out. The major field experiments associated with this research program are listed in Table 1 and discussed below.

One-Ton Cratering Series

The MIDDLE COURSE II cratering series provided much pertinent information on the effect of stemming on crater dimensions and collateral effects. The cratering data from this experimental series combined with the results of the MIDDLE COURSE I series provided a complete set of cratering curves for fully-stemmed 1-ton aluminized ammonium nitrate slurry explosive charges in a wet, weak to intermediate strength sandstone. The optimum depth of burial was determined to be about 18 feet. The apparent crater radius and apparent crater depth at optimum depth of burial are about 23 feet and 13 feet, respectively.

The effects of stemming on crater dimensions in this preliminary series revealed the following trends:

1. At optimum depth of burial for fully-stemmed charges (18 feet), craters produced from unstemmed or water-stemmed charges are smaller than fully-stemmed craters.

2. The crater radii for unstemmed or water-stemmed detonations are about equal and about 10% less than would be predicted for a fully-stemmed detonation.

3. Crater depth is more significantly affected by stemming conditions than is radius. Apparent crater depth of a water-stemmed detonation would be about 15% percent less than the depth excavated by a fully-stemmed detonation. Unstemmed charges appear to produce craters which are 20-25% more shallow than craters from fully-stemmed charges.

4. At depths of burial much greater than optimum for the fully-stemmed case, water-stemmed charges produced craters which were substantially larger than those produced by fully-stemmed or unstemmed charges.

The influence of geology and soil conditions on cratering is very pronounced for 1-ton charges at this site. Local site conditions such as overburden depths and discontinuities in the rock create asymmetrical craters and ejecta distribution patterns. These variations would be overridden by larger charges, however.

Ground motion and peak air overpressure measurements obtained during the MIDDLE COURSE II cratering series combined with data obtained from the MIDDLE COURSE I series led to the following conclusions:

Table 1. Current Military Cratering Tests Conducted by EERL (1970-1973)

Name	Number/Yield	Location	Date	Media	Explosive	Stemming	DOB
MIDDLE COURSE I	6 ea/1-ton	Trinidad, Colorado	Dec 70	Interbedded Sandstone and Shale	Slurry	Stemmed and Unstemmed	Varied
MIDDLE COURSE II	16 ea/1-ton	Trinidad, Colordo	Sep 71	Interbedded Sandstone and Shale	Slurry	Stemmed, Unstemmed, and Water Stemmed	Varied
DIAMOND ORE (II A-1)	1 ea/10-ton	Fort Peck, Montana	Oct 71	Clay Shale	Slurry	Unstemmed	6 Meter
DIAMOND ORE (II A-2)	1 ea/10-ton	Fort Peck, Montana	Oct 71	Clay Shale	Slurry	Stemmed	Approx. 12 Meter
DIAMOND ORE (II A-3)	1 ea/10-ton	Fort Peck, Montana	Oct 71	Clay Shale	Slurry	Stemmed	Approx. 12 Meter
DIAMOND ORE (II B)	1 ea/18-ton	Fort Peck, Montana	Oct 72	Clay Shale	Nitromethane	Unstemmed	6 Meter
DIAMOND ORE (II B)	5 ea/1-ton	Fort Peck, Montana	Oct 72	Clay Shale	Nitromethane	Unstemmed	Varied
DIAMOND ORE (II B)	1 ea/1-ton	Fort Peck, Montana	Oct 72	Clay Shale	Gelled Nitromethane	Unstemmed	18 feet
ARMOR OBSTACLE II (Prechamber)	2 ea/3480#(Avg)	Fort Peck, Montana	Nov 72	Clay Shale	TNT & Slurry	Unstemmed	Approx. 6 Meter
ARMOR OBSTACLE II (Deliberate Road Crater)	2 ea/300#(Avg)	Fort Peck, Montana	Nov 72	Clay Shale	AN & Slurry	Unstemmed	5-7 Feet
ESSEX-1 (Phase 1)	1 ea/18-ton	Fort Polk,* Louisiana	Summer 1973	Wet Soil	Gelled Nitromethane	Unstemmed	3 Meter
ESSEX-1 (Phase 1)	1 ea/18-ton	Fort Polk,* Louisiana	Summer 1973	Wet Soil	Gelled Nitromethane	Unstemmed	6 Meter
ESSEX-1 (Phase 1)	1 ea/18-ton	Fort Polk,* Louisiana	Summer 1973	Wet Soil	Gelled Nitromethane	Stemmed	6 Meter
ESSEX-1 (Phase 1)	1 ea/18-ton	Fort Polk,* Louisiana	Summer 1973	Wet Soil	Gelled Nitromethane	Stemmed	12 Meter

*Subject to Environmental Assessment

1. Peak seismic motions increase with increased DOB.

2. The peak air overpressure data indicate that stemming has a significant effect on the airblast signal. The unstemmed detonations consistently produced higher peak amplitudes than did the fully-stemmed or water-stemmed events.

The fallout simulation program demonstrated that vent fraction can be determined by the tracer method tested and iridium deposition values can be related to fallout dose rate contours. In connection with data reduction, computer codes were developed which will be useful for Project ESSEX and other future test programs.

In addition to the 1-ton cratering program discussed above, DIAMOND ORE, Phase IIB had six each unstemmed 1-ton detonations to obtain a cratering curve for unstemmed detonations in clay shale.

ADM Simulation

EERL is participating in Project ESSEX (called DIAMOND ORE by the Defense Nuclear Agency), a comprehensive study dealing with the effects of subsurface explosions. EERL has specific responsibility for the management and conduct of Project ESSEX-1. ESSEX-1 is a series of cratering tests designed to develop techniques for simulating nuclear cratering detonations using chemical explosives, particularly for the creation of obstacles and barriers.

The amount and type of stemming, local geology, yield, emplacement hole size, and depth of burial employed in the emplacement of a subsurface nuclear device influences the size of the resulting crater and the amount of radioactivity vented into the atmosphere. The magnitude of these influences on crater parameters and the resulting fallout pattern is not known. To formulate an effective tactical employment doctrine for ADM, these effects must be determined. The Limited Test Ban Treaty of 1963 limits the testing of nuclear devices. Thus, these effects have not been determined by cratering experiments employing nuclear devices. Project ESSEX is designed to provide the data required for evaluation of these effects by simulating nuclear cratering detonations using chemical explosives as the energy source. The radioactivity vented will be simulated by mixing quartz particles of known size with the explosive and collecting the vented particles. The quartz particles are coated with an inert tracer material that permits use of neutron activation techniques.

The ADM goals of ESSEX are:

> To provide the Army with accurate and reliable ADM effects data and damage prediction methods so that low-yield ADM's can be confidently employed and the unwanted collateral effects of large-yield ADM's can be avoided. A 90% confidence level of being able to predict a given effect to ±20% is desired.

The experimental program for ESSEX-1 is a continuation of two earlier phases of work, called DIAMOND ORE, Phases I and II.

DIAMOND ORE, Phase I determined the chemical explosive to be used and its basic characteristics. Phase I also developed the data acquisition and analysis procedures for the radioactivity simulation portion of the program.

DIAMOND ORE, Phase II is designed to develop the chemical explosive charge configurations which best model optimum and 6-meter depth of burial nuclear detonations in a stemmed, unstemmed, and water-stemmed configuration. Phase II will also further develop the radioactivity simulation program.

ESSEX-1, Phase I will be the demonstration phase for the DIAMOND ORE Phases I and II and will determine cratering parameters and vented radioactivity for detonations in a tactically significant geologic medium. Phase I will be a series of traced cratering detonations utilizing gelled nitromethane as the energy source. This series will be conducted in the summer of 1973.

Figure 8 shows the logic flow for our work in ADM simulation. The equation-of-state for the material at Fort Peck was known. This was coupled with the equation-of-state for the nuclear device and a computer model was used to compute the characteristics of the resulting crater. The equation-of-state for the nitromethane, a high explosive, and the geologic material were used in the same computer program and the explosive configuration was varied until the crater matched that from the nuclear calculation. This then provided the design for our Phase IIB detonations. The results of these experiments will be used to evaluate the design and possibly form the basis for a new design for ESSEX-1.

Bulk Commercial Explosives in the Battlefield

Slurry explosives have demonstrated their applicability, effectiveness, and versatility for a large number of military applications. The extent of these applications is severely handicapped in the area of target destruction due to the lack of testing and experimentation of slurry explosives for this particular application. Immediate adoption by the tactical commander of some of the other conceptual application proposed in Figure 7 would also prove to be very difficult. There are three basic reasons for this problem:

1. Procedures have not been established which will easily enable the commander to determine what explosive he needs to satisfy his requirements. It has been shown that the proper selection of an explosive for a project depends on many factors which are just beginning to be understood. To take advantage of the versatility of slurry explosives an ideal tactical packaging configuration must be specified, as well as a set of formulas for on-site hand and machine mixing requirements.

2. A majority of the projects suggested for explosive excavation using slurry explosives will depend upon the tactical commander's ability to rapidly emplace large quantities of slurry explosives in a deep, large-diameter hole. Considering the Army's present ability for drilling or otherwise obtaining deep, large-diameter holes, the tactical commander would be severely hampered in his use of slurry explosives for large excavations. If the Army is to take advantage of the capabilities of slurry explosives within the near future, an accelerated program must be adopted for the testing and evaluation of portable drill rigs similar to those available commercially, capable of creating emplacement holes up to 24" in diameter and 100 feet deep.

3. Before many of the larger explosive excavation and target destruction projects can be approved and associated design procedures accepted as a part of official Army doctrine to be included in appropriate Army manuals, an extensive prototype experimentation program must be conducted. Despite the experience that has been gained and demonstrated from using slurry explosives for large civil works excavation projects, there is still a requirement to prove these techniques are applicable for the battlefield of tomorrow.

Realizing the potential capabilities of slurry explosives and the Army's present limitations for exploiting this potential, Waterways Experiment Station (WES) has developed a 5-year research proposal which addresses the feasibility of slurry explosives as a military engineering tool. The proposal formulates the Military Engineering Applications for Commercial Explosives (MEACE) Program and is directed specifically toward evaluating the potential of slurry explosives for future military applications such as barriers, target destruction, and construction. Keeping in mind the Army's present shortcoming, the proposal aims directly at explosive and emplacement rig selection, cratering and the associated effects, and finally, application experimentation. Before this proposal will be approved by OCE there are still a number of questions which must be answered. Programs such as ARMOR OBSTACLE II, outlined in Table 1 and discussed below, will help. WES has been requested to conduct a study during FY 73 for answering questions such as:

1. What is the anticipated distribution of Military Engineering applications for explosives in a typical theater of operations?

2. What explosives systems are presently being used for these applications?

3. What other explosives systems can be considered for these applications?

4. What are the international standardization considerations?

5. With regard to each application, what are the relative merits of the present and potential explosives systems?

Ultimate implementation of the 5-year proposal and the complete adoption of the concepts of explosive excavation may provide today's modern army with the blast for tomorrow's theater of operations.

Mobility Tests

Four recent field experiments portray some applications of bulk explosives for battlefield use. Project DIAMOND ORE, though actually a nuclear simulation program, has demonstrated the capability of slurry explosives to produce tactically significant craters. Projects TANK TRAP[5] and ARMOR OBSTACLE I have evaluated craters produced by large chemical explosive charges as tactical vehicular obstacles. Project ARMOR OBSTACLE II reevaluated the Army's deliberate road crater and prechamber obstacle designs and several alternate designs using slurry explosives. These projects mark the initial effort in evaluating slurry explosives for the theater of operations.

Project TANK TRAP was a joint research effort of the U. S. Army Engineer Nuclear Cratering Group (now EERL) and the Land Locomotion Laboratory of the Army Tank Automotive Center. The purpose of Project TANK TRAP was to determine the capability of selected tactical vehicles to traverse craters typical of those which could be produced with ADM. The vehicles included in the test program were the M-60 Tank, M-113 Armored Personnel Carrier, and an articulated two-unit general purpose vehicle called the POLECAT. The scope of the testing program did not include the use of engineering effort (earth-moving, bridging, surface stabilization, etc.) to assist the entry and exit of the vehicles. Project TANK TRAP was conducted in existing craters that have been created in the Nevada Test Site with chemical explosives to model possible nuclear tests. The JANGLE-U crater was produced nuclearly.

Specific craters in which the vehicle trafficability study was conducted are described in Table 2.

TABLE 2

Description of Test Craters, TANK TRAP

Code Name	Cratering Medium	Yield (Kiloton)	Depth of Burial ft	Radius R_a, ft	Depth, D_a, ft	Lip Height ft	Slope Angle
SCOOTER	Alluvium	0.5/HE	125	155	75	12.5	30-35%
JANGLE-U	Alluvium	1.2/NE	17	130	53	8	20-32%
Pre-SCHOONER BRAVO	Basalt	.02/HE	51	49	25	9	27-30%

These crater sites were selected for the trafficability study for the following reasons:

1. The craters are representative of those that could be produced by ADM detonated at very shallow depths of burial (JANGLE-U) and near optimum depths of burial (SCOOTER and Pre-SCHOONER BRAVO).

2. The media in which the craters were produced bracket a wide range of materials that are encountered in nature (dry soil to hard rock) and, therefore, the test results could be used to predict the performance of tactical cehicles in several different types of material.

Based on the results of Project TANK TRAP it was concluded that:

1. Craters formed in dry soil by the detonation of explosives at the surface and at very shallow depths of burial do not present significant trafficability problems to tracked tactical vehicles. This is primarily because this type of crater has flat slopes and is relatively shallow.

2. Craters formed at or near optimum depth of burial in dry soil are a trafficability obstacle to tactical tracked vehicles. The slopes of this type of crater are greater than the slopes of very shallow depth of burial craters.

3. Craters formed in hard rock such as basalt cannot be negotiated by tracked vehicles without major modification of the crater and/or assistance by heavy duty equipment either mobile or fixed.

ARMOR OBSTACLE I was conducted in conjunction with DIAMOND ORE IIA during the fall of 1971 at Fort Peck, Montana. The three craters produced by the DIAMOND ORE shots were tested as to their actual obstacle effectiveness. Test equipment included an infantry squad, one M113 Armored Personnel Carrier, and an M48 Tank. The medium involved was a Bearpaw clay shale.

The craters formed by an aluminized slurry explosive in DIAMOND ORE Phase IIA proved to be excellent obstacles when evaluated in ARMOR OBSTACLE I. Not only was it extremely difficult or impossible for the tank to exit these craters, but remedial dozer action proved only marginally effective and quite time consuming. The crater widths in all three cases exceeded the capacity of any known, rapidly installable fixed bridging. Strategically placed, the obstacles demonstrated in Project ARMOR OBSTACLE I would not only impede the enemy's advance, but have the potential to create significant tactical or logistical delays.

Project ARMOR OBSTACLE II conducted in the fall of 1972 at Fort Peck, Montana, was a series of cratering mobility tests, designed to evaluate and improve upon the existing prechamber barrier concept and the Army's deliberate road crater technique using slurry explosives. Project ARMOR OBSTACLE II is the first of a series of experiments geared to specifically investigate the feasibility, design and employment concepts for utilizing slurry explosives for creating barriers to impede enemy movement; destroying targets such as dams, bridges and culverts; and improving military engineering construction techniques.

SUMMARY

Large reductions in emplacement and explosive costs have been experienced in the past two years in the process of developing explosive excavation, and further significant reductions appear feasible. The use of chemical explosives are showing progress for simulation of ADM's and for military engineering on the battlefield. Maybe some day, a U. S. Army Officer will say, "Within a few days we built a ditch greater than 83 kilometers long."

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5. Project TANK TRAP, U. S. Army Engineer Nuclear Cratering Group, Livermore, California, NCG-TR-17, June 1969.

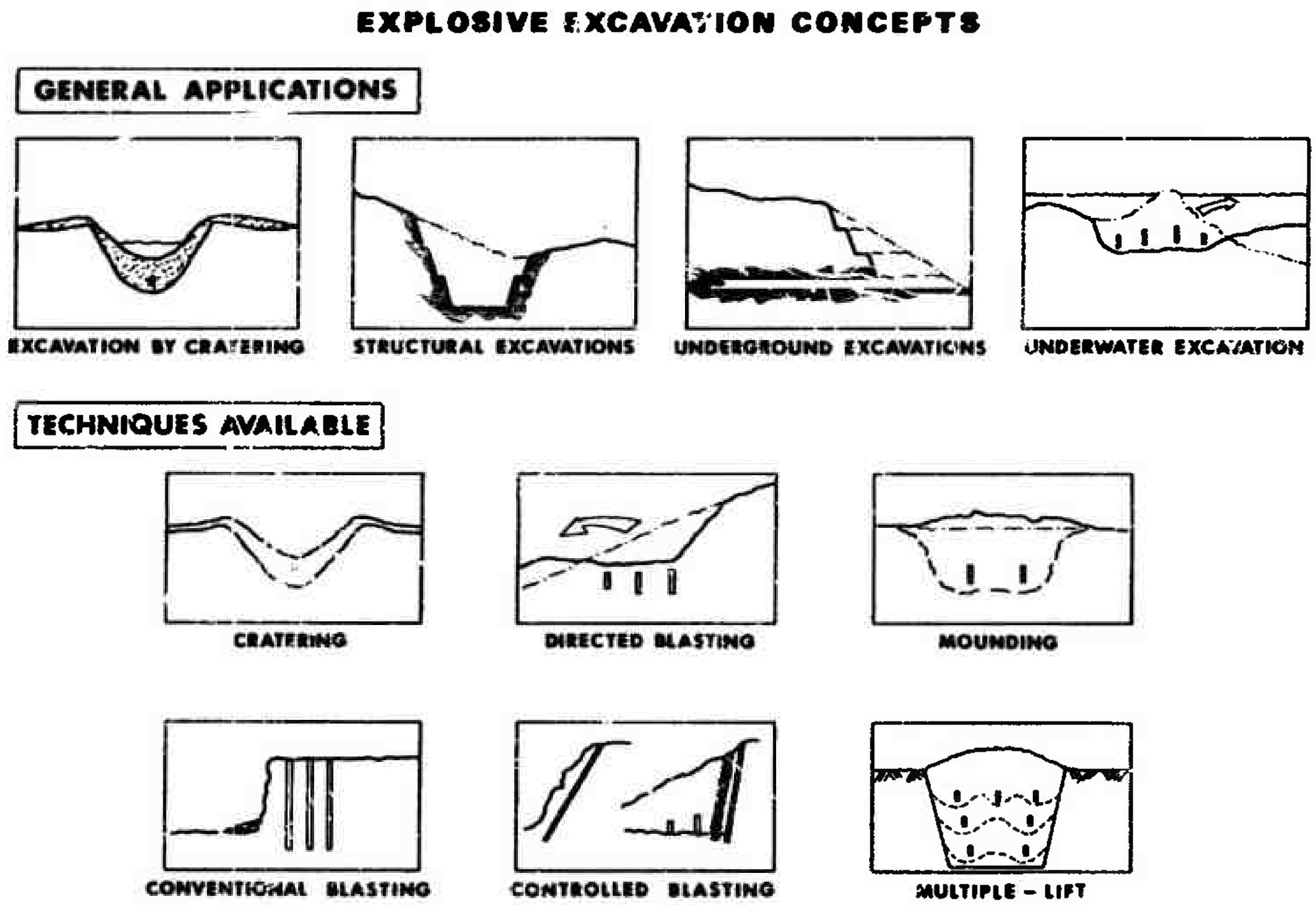

Fig. 1 - Explosive excavation concepts.

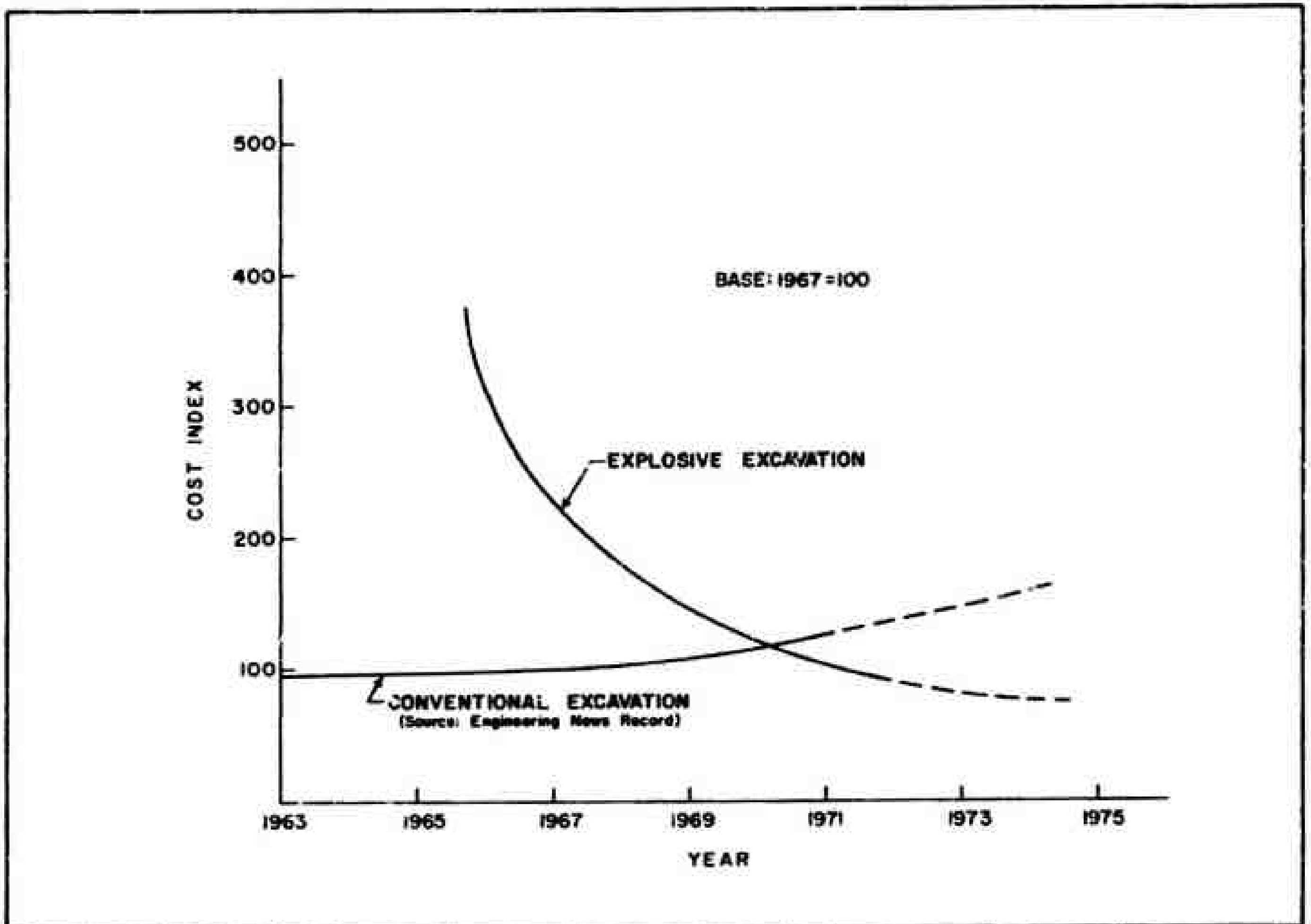

Fig. 2 - Comparison of cost trends of explosive and conventional excavation.

Fig. 3 - Explosively excavated Pre-Gondola channel (boat is 42 ft in length)

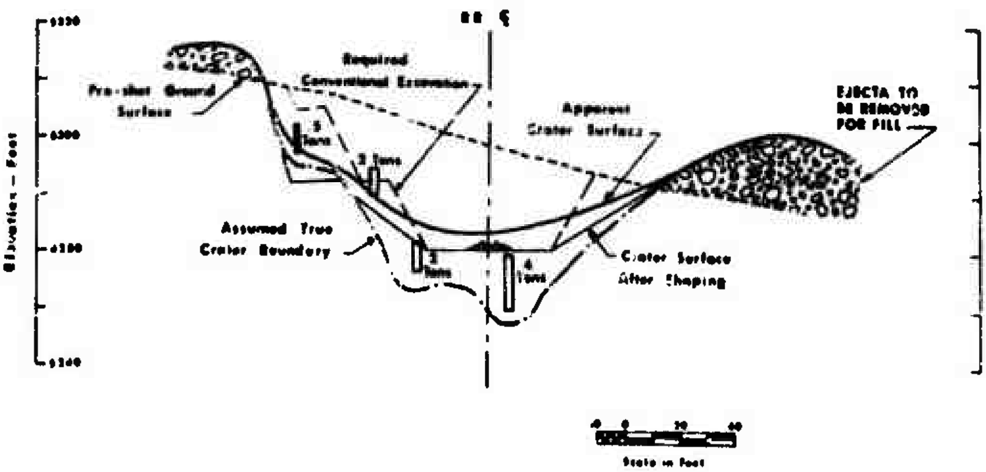

Fig. 4 - Design for typical cross section of Trinidad railroad cut RR-3.

Fig. 5 - Trinidad railroad cut RR-3 immediately after detonation.

Fig. 6 - Trinidad railroad cut RR-3 after dressinq.

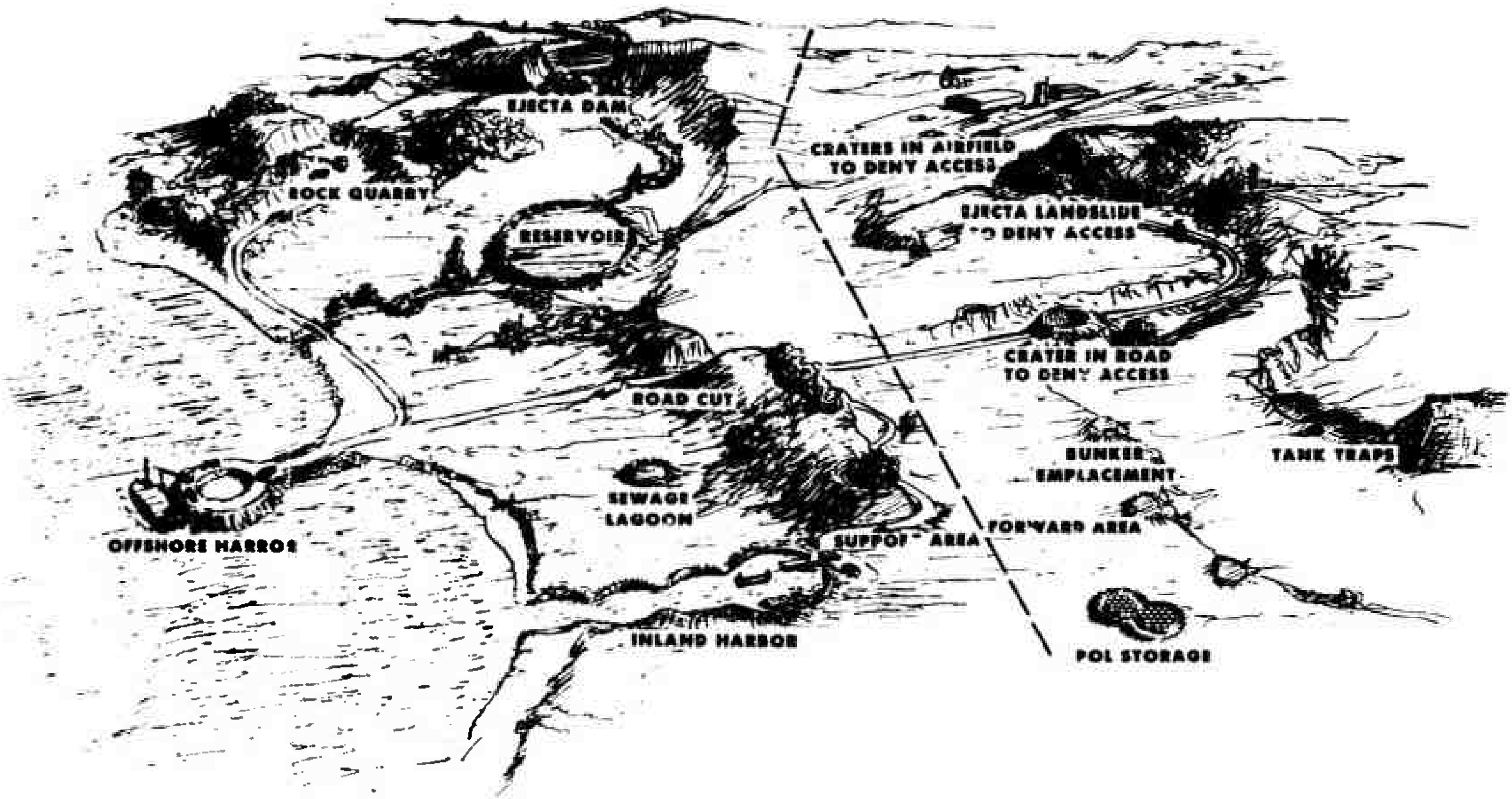

Fig. 7 - Explosive Excavation in the Theater of Operations

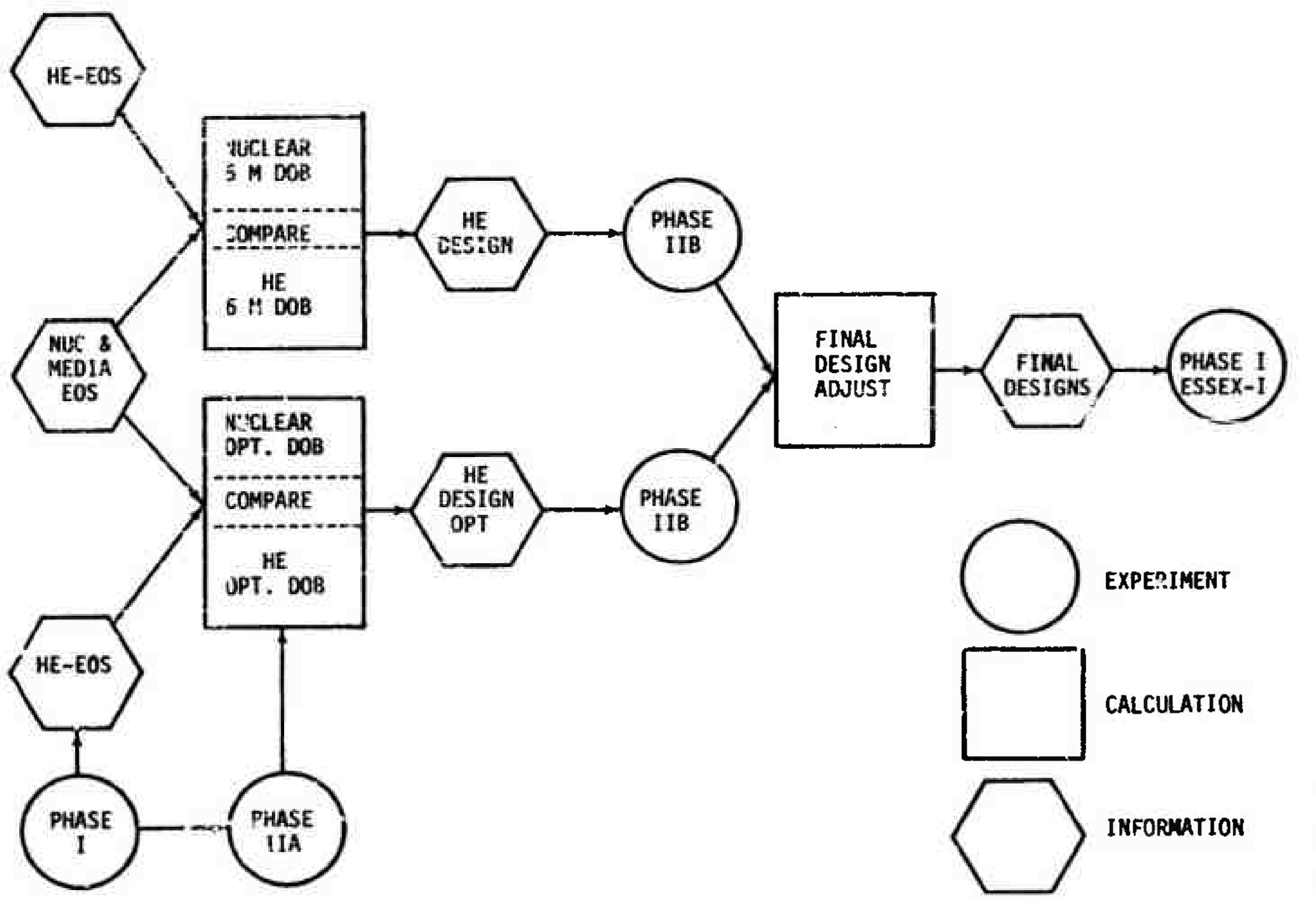

Fig. 8 - Flow Diagram for ADM Simulation

EXPLOSIVES SAFETY AND THE NATIONAL ENVIRONMENTAL POLICY ACT

Donald E. Lawyer
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Gentlemen, it gives me a great deal of pleasure to be here with you this morning to discuss briefly some aspects of the National Environmental Policy Act and as it may relate to the subject of this conference - explosives safety.

Proliferation of Federal and State legislation and regulations has made it essential for each Federal executive department to exert leadership and to examine carefully the manner in which they carry out their many activities, to insure that these activities will be in compliance with environmental laws and regulations, and also that they are compatible with the environment.

The most significant piece of environmental legislation in recent years is the National Environmental Policy Act, better known as "NEPA", which the President signed on January 1, 1970. NEPA requires that consideration of the environmental consequences of each Federal action be incorporated into the agency planning and decision-making procedure. This is specified in Section 102(2)(c) by the requirement for the preparation of a detailed statement which includes:

(i) the environmental impact of the proposed action;

(ii) the adverse environmental effects which cannot be avoided should the proposal be implemented;

(iii) alternatives to the proposed action;

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be involved.

Another important aspect of NEPA is that it established a three-member Council on Environmental Quality to procedurally implement NEPA and continually monitor the actions of the Federal agencies in this regard. CEQ provides policy guidance to the President on all matters affecting the environment. The CEQ has issued detailed "Guidelines" on NEPA and more specifically on the preparation and coordination of environmental statements.

These "Guidelines" require the preparation of a statement whereby the environmental impact of a proposed action is likely to be controversial regardless of the agency's conclusion concerning the actual environmental impact. The "Guidelines" also provide that to the fullest extent possible no administrative action shall be taken sooner than 90 days after the draft statement has been circulated for comment and made available to the public or sooner than 30 days after a final statement has been filed with the CEQ.

To put this into proper perspective, let's take a specific example. This project called "Mixed Company" pertains to the detonation of high explosives in Colorado to provide data on the cratering and ground motion effects of a very large explosion in a layered medium and to provide a blast environment for the evaluation of military target response. The test will be a 500-ton TNT detonation spherical charge to be placed tangent to and above the ground.

The agency responsible assessed the environmental aspects associated with the test and concluded they would be insignificant and transient in nature. These effects were: construction activities, products of the explosion, dust cloud, crater and ejecta, noise, air blast, and ground shock. Because these environmental effects were considered to be minimal, an environmental statement was not considered necessary; however, due to the public reaction and controversy developed with public notification of the proposed test, a draft environmental statement was prepared on the test, circulated to the CEQ and to the Federal and State agencies with jurisdiction by law or special expertise for environmental matters and made available to the general public. All comments received were given careful consideration and a final environmental statement prepared and filed with the Council on Environmental Quality. To my knowledge there has been no comment raised in regard to the final statement or the proposed test.

The courts have been very active in regard to NEPA and a general trend seems to indicate that they are very liberal in their definition of "major action" and "significantly affecting the quality of the human environment." The courts look upon NEPA as a full disclosure law and have been very forceful in their decisions that insure that all environmental impacts (both beneficial and adverse) are discussed. They also interpret the NEPA to have the agency fully consider all possible alternatives.

The Department of Defense has implemented NEPA and the CEQ "Guidelines" with Directive 6050.1 which requires that environmental considerations be initiated with the planning of a proposal or action and be a part of the decision-making process. We are now preparing environmental assessments and in many cases detailed environmental statements on our actions including a much more thorough analysis of different alternatives.

The activities of research, design, manufacturing, and disposal of explosives are all subject to the application of NEPA and for deliberate and full consideration of the environmental consequences of each. Recent examples of this requirement are the handling and disposal of herbicides, chemical and biological weapons, and conventional weapons. At the present time, we are now requiring adequate demilitarization procedures as part of our procurement of ordnance material because we can no longer dump them when they become obsolete.

I think with this background, I might be able to expand more on this new environmental concern and as it relates to your particular area of interest by answering whatever questions you might have.

Thank you.

HAZARD INFORMATION SYSTEM DOCKET NO. HM-103

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Thank you, Al. Friends. It is a real pleasure for me to be here with you.

I would like to ask a favor of you. Inasmuch as this presentation deals with a public docket, it is necessary that I obtain a record of those present. Will you be so kind as to sign the sheet being circulated? Thank you very much.

The Hazard Information System, or HI System in abbreviated form, as presented in Docket No. HM-103, is a culmination of hopes, complaints, suggestions and proddings by many persons, representing the full spectrum of hazardous materials (HM) activities, including the public.

For many years, comments about the deficiencies of the regulations in this regard, while maybe not ignored, were not resolved. The Airlie House Conference in 1969 clearly pointed out the need for improved communications as to the hazards of materials during transport and the need for an emergency response information system. Action has been underway within DOT since that time to update the system. The Hazardous Materials Control Act of 1970 is probably the single factor most responsible for precipitating action on the HI System--it compressed the time schedule.

The HI System involves labeling, placarding, shipping papers and emergency response information. The system is designed for consistency in all modes of transport. This is essential because of the extensive, and ever-increasing, amount of cargo subjected to inter-modal shipment. Uniformity is always an improvement, because it reduces the chance for confusion, which is a primary cause of accidents.

The HM Regulations do not permit the proper identification of hazards of mixed loads. A key feature of the HI System is that it requires the placarding of vehicles in such a manner as to indicate the significant hazards present. Furthermore, the HM's must be listed first in the shipping papers, if both HM's and non-hazardous items are present.

Related to this is the fact that, with a couple of exceptions in the present system, only one hazard is revealed on the placard or label, when in actuality two or more significant hazards may exist for a particular commodity. The HI System is constructed to convey the multiple hazards of a commodity, if this be the case, or just as clearly that only a single hazard exists.

The existing labels and placards, while not completely void of information, do not in themselves give any help with respect to what emergency action one should take for a given shipment. A very vital part of the HI System is a set of Emergency Response Cards (or handbook pages) which states some do's and don'ts. These cards or handbook are keyed to the labels and placards by the HI number. They also list a phone number to call for further assistance, for example for cleanup and disposal. Figures 1, 2, 3 and 4 illustrate these cards. The 01 category means "Dangerous". Presently, the presence of HM's in a transport vehicle does not have to be disclosed in all cases. For example, placards may not be required now for shipments of certain commodities in a quantity less than 1,000 pounds. The HI System proposes to require a "Dangerous" placard, as explained in Figure 5. The 01 refers to "Dangerous", as mentioned a moment ago. The instructions for 01 are essentially the same as 32--flammable and toxic.

In developing the HI System, we gave much consideration to the people who are involved with HM's in the transportation environment and to interfacing with other Government regulatory organizations such as the Department of Labor, Food and Drug Administration, EPA and the like.

Many people--the public, highway patrols and fire service personnel, to name a few--become involved with HM emergencies. Overall, the number one concern, as far as the system design goes, is for the fire service personnel, because they are the ones who have to deal directly with the HM's. Nevertheless, police and other authorities also can respond from the information conveyed. Judgment is required in any case--the system is intended to permit a better-informed judgment than would otherwise be possible.

The system certainly must be simple enough to understand so that it will be enforceable as a regulation. It must be consistent with and augment the United Nations identification system.

The HI System provides a means for publicizing or advertising the HM transportation aspect of safety to the public in a way never before available to the DOT. This is meant in terms of educating the public--making the public aware of the hazards.

The desire was to get away from a preclearance requirement, as much as possible, by establishing criteria so the shipper could derive the HI numbers for his materials. However, we decided that preclearance should be required for certain special types of commodities, which include the following:

Organic Peroxides--all the known ones being shipped will be classified by DOT and their classifications listed.

Explosives--For the time being, these would be classified according to existing regulations.

Highly and Extremely Toxic Gases.

Self-Reacting and Thermally Unstable Materials.

Water-Reactive Materials.

As individual items are listed by name in the commodity list, DOT will also list their HI numbers.

So much for general background, now let us consider some specifics of the HI System. It consists of a two-digit number, which identifies the significant hazard(s) that the commodity presents in transportation. These numbers appear on labels, placards, information sheets or cards, as we already have seen, and on shipping papers as illustrated in Figure 6. The first digit corresponds to a particular United Nations hazard class.

In order to provide a proper mechanism for the derivation of HI numbers, we are forced to rank hazards in order to assign the numbers. However, let me strongly emphasize that any such ranking is only for the purpose of assigning HI numbers. It in no way implies the relative risks under any given set of circumstances. I cannot over-emphasize this point. The second digit identifies the other significant hazard(s).

The zero, as a second digit, means that there is no significant hazard other than that indicated by the first digit. Generally, the 9, as a second digit, is meant to imply the highest degree of hazard for that series. The basic series are, as follows:

10--Explosives
20--Gases
30--Flammable and Combustible Liquids
40--Flammable Solids
50--Oxidizers
60--Poisons
70--Radioactive Materials
80--Corrosives
90--Reserved and would be used for miscellaneous materials

Altogether 59 of the 99 possible numbers have been assigned to individual hazards or combinations. We made a determined effort to keep the total number low. Table 1 and Table 2 list some of the numbers and what they stand for.

Now let us look at some examples of the HI System features. Figure 7 shows both a placard and a label for a flammable liquid which carries the number 35. It is also corrosive and either self-reacting or thermally unstable. Several levels of communication are evident. The first is symbology, which is an international designator for fire. Below the symbol is the key word that denotes the basic class, flammable. Next we notice the red color which we associate with fire. At the bottom is the HI number, which further categorizes the hazards and is the key to obtaining emergency response information.

The general public will not know exactly what the numbers mean. The shipper will, because he is responsible for assigning and/or inserting the proper number.

Docket No. HM-103 states tentative definitions for the various hazard classes. Some of these are going to have to be modified in all probability, because at this time we still have research underway or contemplated to help us improve the definitions of hazard classes and degrees of hazard therein. We intend to provide quantitative criteria for defining these hazard classes and degrees, so that confusion will be eliminated and the shipper will know exactly how to designate his product, if it is one to which he has to assign the HI number. The same holds true for those people in DOT who have the responsibility for classifying the special types of commodities mentioned a little earlier.

By permitting the shipper to fill in the second digit by printing, pasting, etc., the shipper need only keep a few basic types of labels and placards in stock, thus reducing the cost.

The proposed HI numbers for explosives are 11 for Class C, 15 for Class B and 19 for Class A. However, it has been suggested that we revise this proposal to use 11, 12, 13 and 14, which would respectively correspond to the UNO explosive subdivisions of 1.1, 1.2, 1.3 and 1.4. The 1.4 represents a minor hazard comparable to our Class C; 1.3 is similar to Class B; while 1.2 and 1.1 would be Class A items--the difference being that 1.2 stands for progressively reacting and fragmentation hazard and 1.1 for true mass detonation hazard.

It also has been suggested that we use numbers that would not conflict such as 15, 18, 19.

In the twenty-series we find both compressed and liquefied gases--both flammable and non-flammable ones. Number 20 conveys the meaning that there is nothing more than a container rupture hazard due to the gas pressure.

Number 21 indicates a corrosive gas which is not toxic, but is irritating.

Number 22, as shown in Figure 8, is oxygen. There is some question about what to do with oxygen--whether to give it a number all its own, or have an oxidizer gas category that is not also poisonous. We are determined that it will not be identified as a non-flammable compressed gas, because it is not properly described that way.

Figure 9 shows number 24, which is for a flammable gas that is corrosive.

Chlorine is designated 26, which is a non-flammable poison gas. Chlorine is somewhat of a special case.

Number 27, is for an oxidizer gas that is poison, while the next one (Figure 10), containing 28 represents a flammable poison gas.

We find pyroforic liquids included in the thirty-series, along with flammable and combustible liquids. Number 30 literally covers thousands of materials.

We can point out an important feature of the HI System, namely, that it lends itself to verification of the commodity involved. Let us take acetone, which carries the number 30, and acetone cyanohydrin the number 67. Let us assume that a person calls in on the emergency response phone number and says "All I can make out on the shipping papers is acetone and the HI number on the placard is 67." Right away, the person at the other end of the line would recognize that the two do not jibe, and he would start asking for more details. By the same token, if the name and number do check, there is an added degree of assurance. In the Dunreith, Indiana case, acetone cyanohydrin was thought to be acetone and serious problems resulted. One cannot say absolutely that the HI System, had it existed, would have prevented that situation. However, it certainly is possible.

To illustrate the importance of the second digit with respect to affecting emergency action, let us consider acrolein, as seen in Figure 11 to be a number 36. If it were not a flammable liquid, it would be a poison B, as the information on the HI card in Figure 12 indicates. If it were involved in a fire, it would be thermally unstable. Figure 13 shows some more details of the HI card for this material. All three hazards indicated are significant for acrolein.

Included in the forty-series, which is for flammable solids, we find pyroforic and water-reactive commodities--a "W" with a line through it conveys the meaning, Do Not Use Water. Figure 14 has a 44 and indicates this feature.

Next we see in Figure 15 a 41, which represents a poisonous flammable solid.

The number 50 means the material is an oxidizer. Number 51 means a corrosive oxidizer.

Number 57 designates an organic peroxide, while 58 in Figure 16 indicates that the organic peroxide requires refrigeration during transport. If cooling capability is lost, the hazard is much more severe than that presented by an ordinary organic peroxide. Number 59 signifies that the item is a critical hazard--very sensitive. When one thinks about this designation, he has a tendency to think about explosives at the same time. Situations like this are what have led us to study the interrelationships between explosives, organic peroxides, flammable solids and oxidizing materials-- the subject of a current investigation. At least one organic peroxide has been banned in the past and, possibly, some others will in the future, at least in certain forms.

The sixty-series covers poisons. Figure 17 is for 61, which means poison, highly toxic and combustible. In 64 and 67 we deliberately point out toxicity by the skin contact (dermal) route, because most people think in terms of inhalation toxicity or poisoning by swallowing the materials and tend to overlook the skin contact hazard, which is a real one from the transportation standpoint

The radioactive materials (RAM) are covered in the seventy-series. We see in Figure 18 number 74 which is for a pyroforic RAM. In the case of uranium hexafluoride, which is numbered 78, the toxic and corrosive properties are sometimes more critical than the fact that it is a RAM.

Number 80 is for corrosives only. In this series we have introduced a new designation, HOD, which stands for Heat Of Dilution. Number 87, as shown in Figure 19 is one of these corrosive HOD's with combustible and poisonous properties also. A material is so-designated, if, when it is diluted at a weight ratio of 1-to-1 with water, the temperature rise is greater than 80 degrees F.

Now let us discuss placards a little more. There are diamond-shaped placards and rectangular ones proposed. To some degree the diamond placard is a larger version of the labels. The rectangular placards for explosives and poisons are a unique design, based upon information

developed in a contract study that the Office of Hazardous Materials had with Northwestern University (Contract DOT-OS-00042). The design presents the information as a target--having the information contrasted, makes it standout. Figures 20 and 21 represent Class A and Class B explosives, respectively.

I have examples of labels and placards with me if anyone desires to examine them.

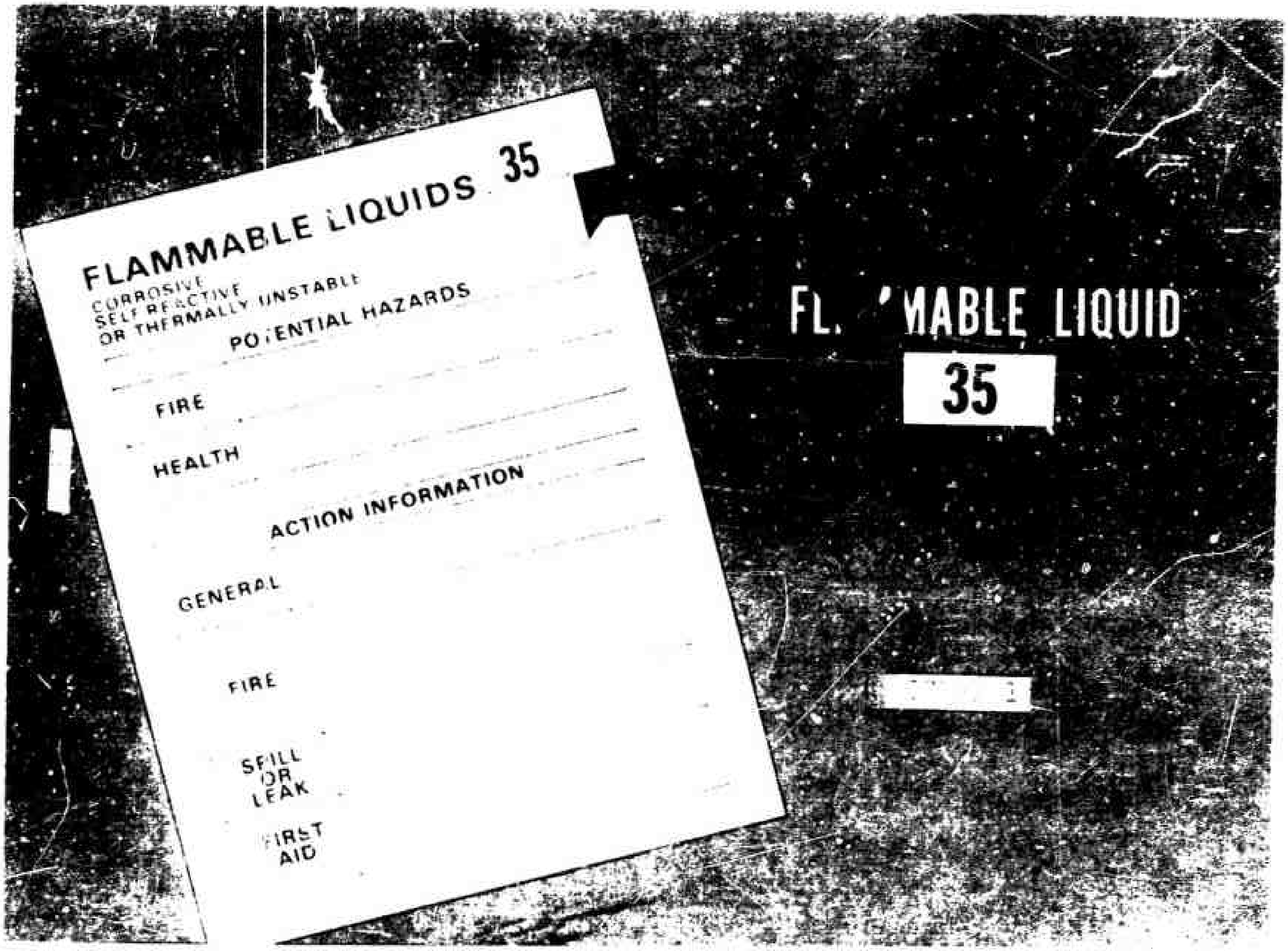
Some people say the system says nothing about quantity and, therefore, it does not deal with risk. Neither does any other system. All we can do is point out that the hazards are there, but the degrees, based upon quantity and environmental conditions, would be extremely difficult to convey.

The Safety and Environmental Protection Working Group of the JANNAF is working up a variation of the hazard information cards for spills of certain liquid propellants. These cards will have exclusion distances for toxicity, fireball and fragmentation based upon quantity. If this proves successful, it is possible that the HI System could be modified to accommodate these additional features. At best, that would be quite some time in the future, because it would be a gigantic task to obtain the necessary technical data.

The comment period for Docket No. HM-103 has been extended to November 14, 1972. All but mixtures, N.O.S. materials and solutions will have HI numbers listed in the commodity list.

Only one comment to date has dealt with the HI cards themselves.

Thank you for your attention.



FLAMMABLE LIQUIDS 35
CORROSIVE
SELF REACTIVE
OR THERMALLY UNSTABLE
POTENTIAL HAZARDS
FIRE
HEALTH
ACTION INFORMATION
GENERAL
FIRE
SPILL OR LEAK
FIRST AID
35

01 DANGEROUS 01

CONTAINS HAZARDOUS MATERIAL

Get the shipping papers.
They should contain a hazard information number for each listed hazardous material in the vehicle or containers.
If shipping papers are not available, use the following for minimum guidance.

01 IMMEDIATE ACTION INFORMATION 01

GENERAL	No unnecessary personnel. Keep upwind, identify and isolate hazard area. Wear self contained breathing apparatus and full protective clothing.
FIRE	On small fires, use dry chemical or carbon dioxide. On large fires, use standard firefighting agents. Cool containers with water from maximum distance. Continue cooling after fires have been extinguished. Move exposed containers from fire area, if without risk.

FIGURE 3

FIGURE 4

01 IMMEDIATE ACTION INFORMATION 01

GENERAL	No unnecessary personnel. Keep upwind, identify and isolate hazard area. Wear self contained breathing apparatus and full protective clothing.
FIRE	On small fires, use dry chemical or carbon dioxide. On large fires, use standard firefighting agents. Cool containers with water from maximum distance. Continue cooling after fires have been extinguished. Move exposed containers from fire area, if without risk.
SPILL OR LEAK	Within hazard area, eliminate ignition sources. No flares, no smoking. No open flames. Stop leak, if without risk. Use water spray to reduce vapors. Use noncombustible absorbent material (sand, etc.) to collect small spills. Dike large spills for later disposal.
FIRST AID	Remove to fresh air. Call physician. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. In case of contact with material or water solution, immediately flush skin or eyes with running water for at least 15 minutes. Remove contaminated clothing and shoes. Keep patient at rest.

Obtain shipping papers.
For additional information, disposal and cleanup instructions instructions, call: (800) 424 9300.
Immediately report pollution or contamination to proper authorities.

(B) FOR AGGREGATE QUANTITIES OF MATERIALS IN ONE SHIPMENT OF LESS THAN 1,000 POUNDS GROSS WEIGHT, THAT BEAR THE SAME HAZARD INFORMATION NUMBER, A DANGEROUS PLACARD MAY BE USED IN PLACE OF THE PLACARD SPECIFIED IN PARAGRAPH (A) OF THIS SECTION, EXCEPT THAT THE PLACARD SPECIFIED IS REQUIRED FOR ANY QUANTITY OF——

(1) A HAZARDOUS MATERIAL IN A CARGO TANK OR TANK CAR, AND

(2) A HAZARDOUS MATERIAL ASSIGNED ONE OF THE FOLLOWING HAZARD INFORMATION NUMBERS:

15,19,

26,27,28,29,

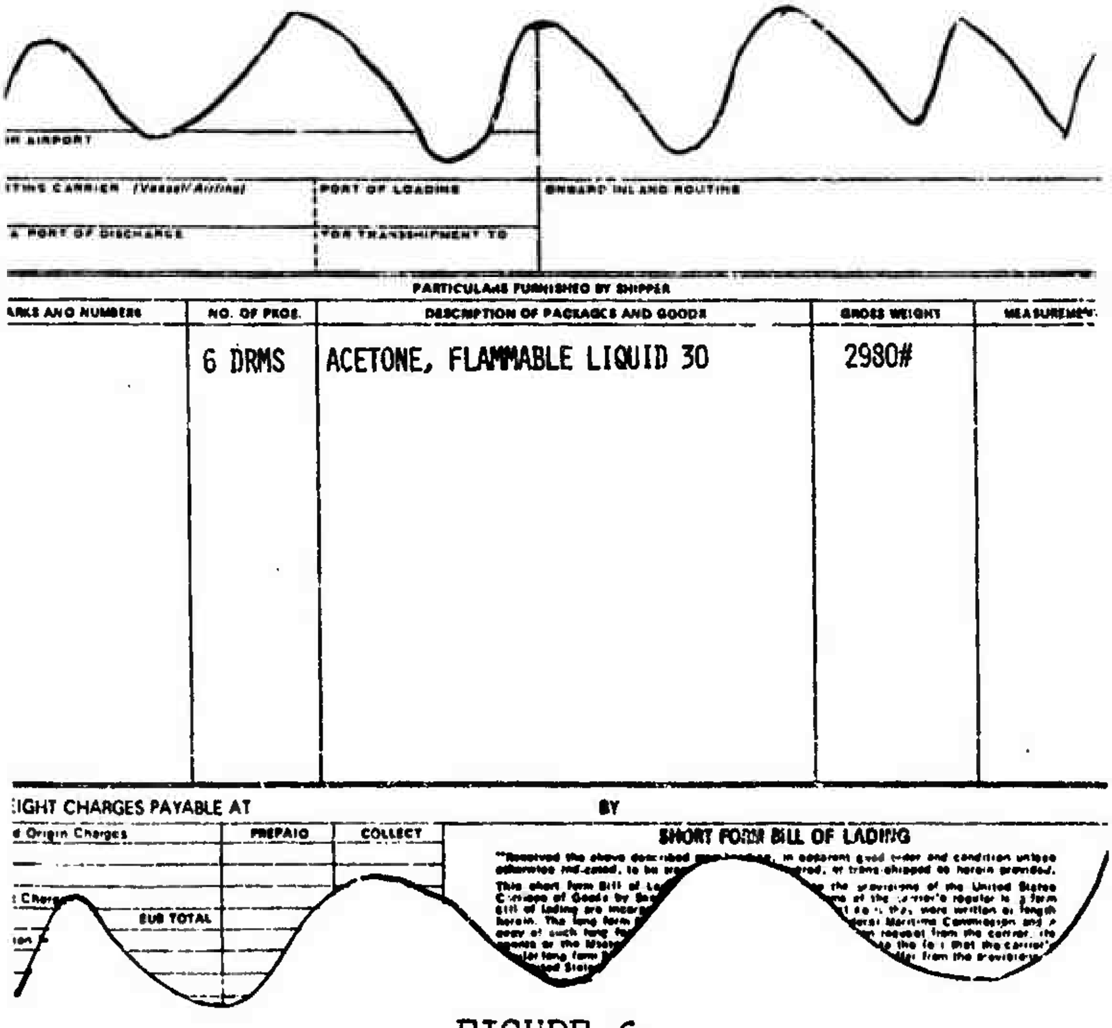
44,45,46,

58,59,

62,64,65,67,

71,72,73,74,78,79

FIGURE 5



IR AIRPORT

ITING CARRIER (Vessel/Airline) | PORT OF LOADING | ONWARD INLAND ROUTING

A PORT OF DISCHARGE | FOR TRANSSHIPMENT TO

PARTICULARS FURNISHED BY SHIPPER

ARKS AND NUMBERS	NO. OF PKGS.	DESCRIPTION OF PACKAGES AND GOODS	GROSS WEIGHT	MEASUREMEN
	6 DRMS	ACETONE, FLAMMABLE LIQUID 30	2980#	

IGHT CHARGES PAYABLE AT BY

d Origin Charges	PREPAID	COLLECT
t Charges		
SUB TOTAL		

SHORT FORM BILL OF LADING

FIGURE 6

Table 1

30---COMBUSTIBLE OR FLAMMABLE LIQUID

31---FLAMMABLE LIQUID--CORROSIVE

32---FLAMMABLE LIQUID--POISON

33--

34---COMBUSTIBLE OR FLAMMABLE LIQUID--SELF-REACTIVE OR THERMALLY UNSTABLE

35---COMBUSTIBLE OR FLAMMABLE LIQUID--CORROSIVE--SELF-REACTIVE OR THERMALLY UNSTABLE

36---COMBUSTIBLE OR FLAMMABLE LIQUID--POISON--SELF-REACTIVE OR THERMALLY UNSTABLE

37--

38---PYROFORIC LIQUID

39--

Tabl. 2

60---POISON--HIGHLY TOXIC

61---POISON--HIGHLY TOXIC--COMBUSTIBLE

62---POISON--EXTREMELY TOXIC

63---

64---POISON--EXTREMELY OR HIGHLY TOXIC BY SKIN ABSORPTION

65---POISON--EXTREMELY TOXIC--FLAMMABLE OR COMBUSTIBLE

66---

67---POISON--EXTREMELY OR HIGHTLY TOXIC BY SKIN ABSORPTION

68---

69---

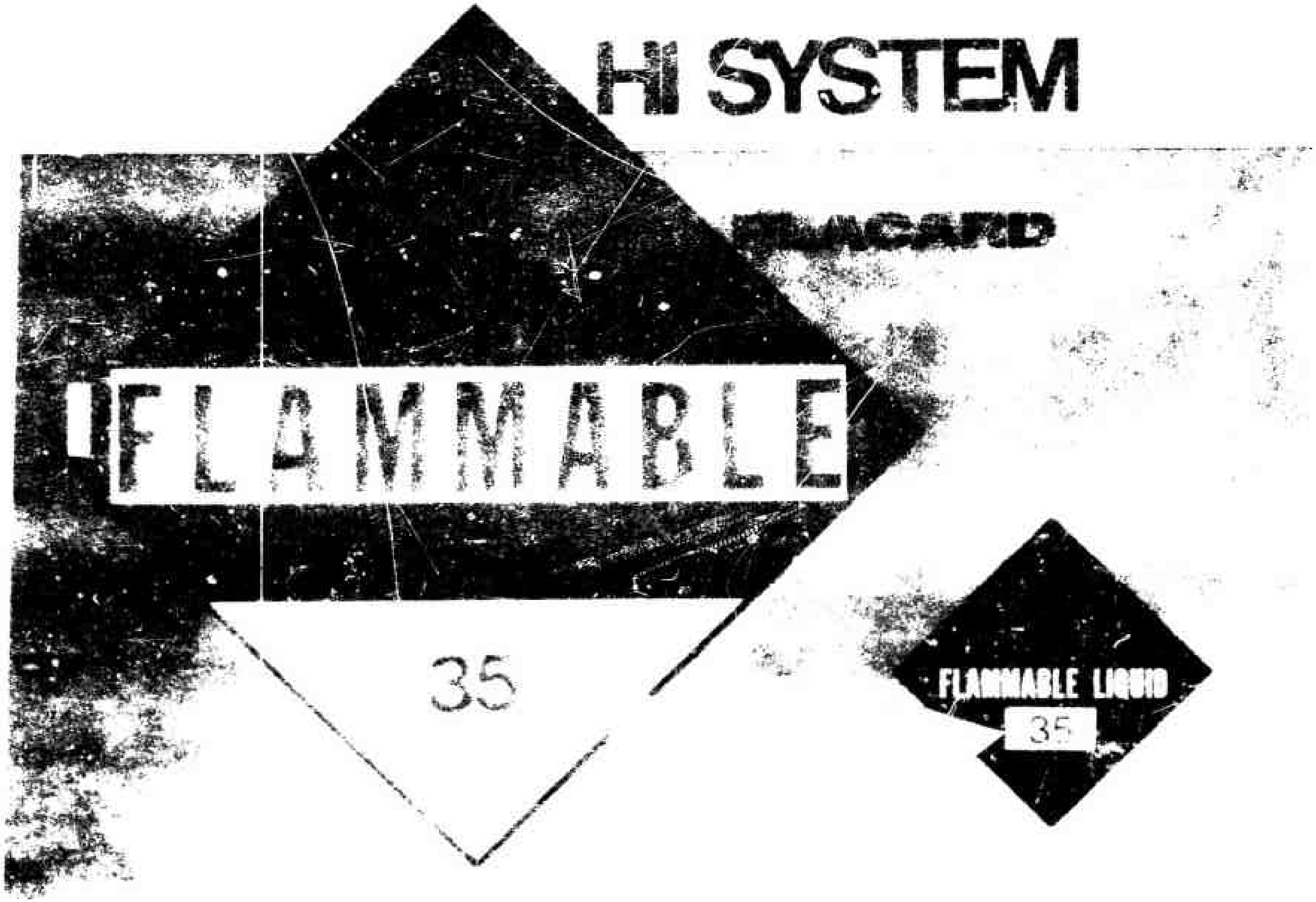

HI SYSTEM
PLACARD
FLAMMABLE
35
FLAMMABLE LIQUID
35

FIGURE 8

FIGURE 9

FIGURE 10

FIGURE 11

POISON, SELF REACTIVE, OR THERMALLY UNSTABLE

POTENTIAL HAZARDS

FIRE	May be ignited by heat, sparks, or open flame. Ignition of vapor may occur at some distance from leaking container. Heated container may rupture violently and produce flying missiles even if water applied for cooling. Vapor entering sewers or other closed spaces may create explosion hazard.
HEALTH	Vapor is poisonous, if breathed. Liquid or solid may cause death, if consumed. Fire may produce poisoning gases. Contact with material may cause severe burns to skin and eyes. Contaminated water or material runoff may pollute water supply.

IMMEDIATE ACTION INFORMATION 36

GENERAL	No unnecessary personnel. Keep upwind. Identify and isolate hazard area. Wear self-contained breathing apparatus and full protective clothing.

FIGURE 12

FIGURE 13

IMMEDIATE ACTION INFORMATION 36

GENERAL	No unnecessary personnel. Keep upwind. Identify and isolate hazard area. Wear self-contained breathing apparatus and full protective clothing.
FIRE	Cool containers with water from maximum distance. Continue cooling after fires have been extinguished. Do not approach ends of horizontal tanks. On small fires use dry chemical or carbon dioxide. On large fires use standard firefighting agents. Move exposed containers from fire area, if without risk. Withdraw from hazard area in case of rising sound from venting safety device. If fire in cargo area is massive or advanced, withdraw from hazard area and use unmanned hoseholder or monitor nozzles.
SPILL OR LEAK	Within hazard area: eliminate ignition source. No flares, no smoking, no open flames. Stop leak if without risk. Use water spray to reduce vapors. Dike large spills for later disposal.
FIRST AID	Remove to fresh air. Call physician. If not breathing give artificial respiration. If breathing is difficult give oxygen. In case of contact with material or water solution, immediately flush skin or eyes with running water for at least 15 minutes. Remove contaminated clothing and shoes. Keep patient at rest.

Obtain shipping papers.
For additional information, disposal and cleanup instructions, call:
(800) 424-9300
Immediately report pollution or contamination to proper authorities.

FIGURE 14

FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 16

FIGURE 19


EXPLOSIVES A
19


EXPLOSIVES B
15

CONTAINERIZATION OF EXPLOSIVES

Mr. Harold T. Decot
Naval Ordnance Systems Command
Washington, D. C.

Containerization has revolutionized the commercial shipping industry in the past seven years. The advantages of handling cargo in large modules from producer to consumer with a minimum of individual handling to save time and shipping costs is the driving force. We in the Department of Defense are being forced to modernize our logistic thinking primarily because the break bulk cargo ships that have been used for over one hundred years for transporting ordnance overseas are disappearing. No break bulk cargo ships have been built for the past three years. Old break bulk ships are being converted to containerships. We can no longer adopt a wait and see attitude to see if containerization is really going to be a success. Already all major U. S. and many foreign commercial ports are now equipped with container cranes to load non-self-sustaining ships to handle containerized Military explosives. The Department of Defense has issued policy statements on containerization which state that shipment by container is the preferred method, unless a specific shipment is not cost effective or advantageous to the Military. The development of a container oriented logistics system is a matter of priority in the Department of Defense. It has been determined that we will rely primarily upon the container resources and services of the commercial transportation industry insofar as such support is responsive to Military requirements. Over half of all Military shipments are now made in containers. Total DOD containerized cargo last year approximated 3.6 million measurement tons, only 10,000 measurement tons were explosives. A study recently proved that DOD realized an average savings of $14.00 per measurement ton in transportation cost alone during FY 71 by shipping in containers rather than break bulk, this amounted to an annual savings of over fifty million dollars.

Containerization in its simplest form is the combining of twenty 4 foot cubical pallet loads into 8 foot by 8 foot by 20 foot module. A common container has a twenty ton capacity or 40,000 pounds. As a safety precaution the Coast Guard has restricted explosive loads to 80% of this capacity. For quantity distance consideration, we use 40% of this for net explosive content. The 8 foot by 8 foot by 20 foot container physically occupies thirty-two measurement tons however, our dense ammunition usually occupies only fifty percent of this cube. There are obviously many advantages for containerizing explosives, not the least of these being the marked reduction in man-handling small units, each of which increases the chances for an accident. Ammunition Depots

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and explosive loading ports of the future should no longer be a clutter of boxes and bags but all in sleek shiny containers in computer assigned spaces ready for intermodal movement by truck, rail, ship and air. Two basic types of containers are available, those with an integral restraining system consisting of adjustable bars that engage into pockets in the container wall and the conventional container with plain walls which require a rather extensive wooden dunnaging system to restrain the ammunition. To test the safety of this dunnaging system for ocean movement the Coast Guard currently requires that each new proposed load be tested by tipping the loaded container to eighty degrees to determine if the cargo is still restrained. Detailed drawings of the dunnaging method are prepared by the Army and Navy. Intermodal shipment of explosives by rail, truck and ship are now approved and practical for restrained containers only. Unrestrained containers can be used if properly dunnaged in all modes except rail where safe practical dunnaging has not yet been developed for container-on-flat-car shipments. The Department of Defense owns approximately six thousand MILVANS, four thousand of them are of the restrained type suitable for handling explosives. In an all out war contingency it is estimated we would require about 180,000 containers to fill the pipe line for ammunition only.

The Navy has developed a comprehensive plan to improve our major ammunition depots and port facilities to accommodate containerization. It involves the expenditure of fifty-six million dollars over the next nine years. Improvements will be made to port facilities at the Weapons Station, Concord and NAD Earle as well as all our major inland depots. One unique feature of this improvement program will involve the construction of open revetments for the storage of ammunition in containers rather than in conventional arch type magazines.

Seven trial shipments of containerized ordnance have been made during the past two years to prove our capability. The last one just completed last month was called operation "Autumn Leaves". It involved the containerization of ten thousand MK 82 Bombs in one hundred and sixty MILVANS at the Naval Ammunition Depot, Crane, Indiana, shipped through the port facility at the Naval Ammunition Depot, Earle, New Jersey, to the Naval Magazine, Subic Bay, in the Philippine Islands. Simultaneously ten thousand MK 82 Bombs were loaded out of the Naval Weapons Station, Concord in seven barges and thirty-six containers on a LASH Ship (Documentary Film of the Operation).

Some of our challenges for the future are to: (a) Develop simplified regulations for handling containerized explosives; (b) Build inland and port facilities throughout the world for handling containerized explosives; and (c) Establish mutual agreements with commercial shippers to handle containerized explosives expeditiously and economically in a future war contingency.

DOCKET NO. HM-103 HAZARD INFORMATION SYSTEM

William Gardner
Munitions Carriers Conference
American Trucking Associations, Inc.

We present the following comments on behalf of the Munitions Motor Carriers, except as to the specific comments presented by National Tank Truck Carriers, Inc. (an affiliated ATA conference) on behalf of for-hire tank truck carriers which transport hazardous commodities in bulk. First, however, we would point out that there is no other group or organization which has a greater, more sincere, or more knowledgeable, concern for all aspects of highway safety, including the transportation by highway vehicles of hazardous materials, than that of the motor carriers represented by ATA. This deep and sincere concern is much more than altruistic in character. It is also selfishly realistic; it is based upon first-hand experience and the lessons learned from daily involvement with the problems which confront users of the highways, and the shipping public dependent upon highway transportation, as well as those charged with the duty of promulgating and enforcing rules and regulations governing the transportation of hazardous materials.

On the basis of this deep concern, ATA and the truck operators it represents have for a long time advocated and supported sound and realistically feasible regulations which have as their purpose the safe handling in highway transportation of hazardous materials under both normal and unusual circumstances. We have offered constructive assistance to the regulatory authorities with the view of encouraging the adoption of regulations which will produce the maximum cost/benefit results for all parties of interest and which will be most effective in furthering safety of highway transportation of these commodities.

We oppose the radical changes in the present existing regulations proposed in the instant docket for the following reasons:

a. There has been no factual showing of need for so drastically revising the present regulations which have been in effect only since July 1, 1967. The current regulation governing placarding highway vehicles was adopted after very thorough consideration and an extended exchange of view among all interested groups. Further, experience in highway transportation in recent years does not disclose a need for changing the requirements.

b. The extreme complexity of the propooed rules relating to placarding highway vehicles, particularly the numerous involved concepts indicated by the numerical component on placards, is such as to make the propored system unworkable. Comprehension of the involved system is beyond the capabilities of many people employed in transport and, consequently, the rules would be completely self-defeating.

c. Even if a factual basis for further improvement in identification of hazard characteristics of shipments were established, the responsibilities of these complex proposals is such that reasonable cost/benefit results could not be attained.

d. The proposal to require display of placards on highway vehicles, regardless of the quantity of hazardous materials transported, would result in such whole-sale display of placards that, as a practical matter, they will become meaningless.

e. Beneficial results can be realized from affirmative action programs within the framework of the existing placarding requirements for highway vehicles.

JUSTIFICATION FOR PLACARDING CHANGES NOT SHOWN

As stated, the trucking industry has a sincere and deep interest in furtherance of measures designed to increase safety in the transportation of all commodities by highway vehicles, including particularly, hazardous materials. ATA represents carriers by highway of all types, including common carriers, contract carriers, and private carriers of property by motor vehicle. For many years the trucking firms represented by ATA and its related state associations and conferences, have been fully aware of and have devoted resources to the development of procedures designed to enhance the safety aspects of truck transportation of these commodities. Therefore, we not only do not oppose but will vigorously support necessary proposals for change if justification is shown and there is a reasonable basis for expectation that the changes proposed will produce safety results which can be justified from a cost/benefit standpoint.

Not only are new materials involved, but the vitally important need for development of operational procedures and the training of personnel impose heavy costs and result in an impairment of operational efficiency. While changes in regulatory requirements from time to time are necessary, the principle should be observed

that major changes should not be undertaken unless there is a clearly established justification. The need for such justification was cited by the National Transportation Safety Board in its study of January 27, 1971, entitled "Special Study - Risk Concepts in Dangerous Goods Transportation Regulations."

In the preamble to the advance notice of proposed rulemaking, the Hazardous Materials Regulations Board said that the need for improved hazard communications "has been the subject of considerable controversy and debate during recent years." The notice states, "it has been pointed out that the communications requirements of the regulations (1) generally are not addressed to more than one hazard; (2) do not in all instances require disclosure of the presence of hazardous materials in transport vehicles; (3) are not addressed to the different hazard characteristics of a mixed load of hazardous materials; (4) do not provide sufficient information whereby fire fighting and other emergency response personnel can acquire adequate immediate information to handle emergency situations; and (5) are inconsistent in their application to the modes of transport.

Justification for the extensive and radical changes proposed in the advance notice has not been established. The present placarding requirements for motor transportation of hazardous commodities became effective July 1, 1967. These requirements call for the use of 11 placards which contain words having a meaning clearly understandable by fire fighting and other emergency response personnel. Prior thereto, there had been a substantial reliance upon use of the word "DANGEROUS" with the result that, in some cases, fire fighters faced with some hazardous goods incidents were not adequately informed. The 1967 revision called for display of specific words, in addition to the word "DANGEROUS," when particularly hazardous materials such as Explosives Class A, Explosives Class B, Poisons (Class A) or certain Radioactive Materials were transported in conjunction with other hazardous materials which called for use of the word "DANGEROUS." We are convinced, on the basis of all information available to us concerning accidents and incidents involving hazardous materials transportation by motor transport, that the present requirements are adequate. The change in regulations which became effective in 1967, made after extensive discussion and consideration on the part of all parties concerned, resulted in placards which clearly identify a number of commodities which, prior to the change, were covered by the word "DANGEROUS."

We have been told that factors exist today which were not given sufficient emphasis or consideration prior to the 1967 modification, and that fire and emergency personnel have indicated a need to know if secondary hazards are present with hazardous materiale. To the contrary, our very extensive contacts with fire and emergency personnel indicate that, to a very great extent, such personnel are not even yet well informed as to the present system. During the early part of 1972 extensive communication with fire departments, rescue squads and police groups in the State of Virginia, in meetings conducted by the Virginia Highway Safety Division, disclosed a aurpriaingly large number of such groups which have not yet been adequately informed concerning the existing placarding system.

In response to our inquiries we have been informed that present accident statistics gathered by the Bureau of Motor Carrier Safety do not afford a true picture of the industry accident record with respect to transportation of these commodities. In short, there is a total lack of information which would form the basis of a justification for the substantial changes propoaed in this docket.

While the advance notice in Docket HM-103 sets forth an entire system entitled, "Hazard Information System" including requirements for labeling of packages, preparation of shipping papera and placarding of vehicles, the preamble states that "the Board believes the most significant concern of persons who would be affected by the proposed requirements is placarding."

It seems clear that the fundamental purpose of placarding vehicles transporting hazardous commodities is to afford reasonably adequate information to police officials, fire fighting personnel, rescue squad members and, to a lesser extent, members of the public who might be present at an accident scene. As to highway commercial vehiclea, placards alao are an indication to personnel of transportation companies as an alerting mechanism with reapect to the presence of the hazardous commodities in vehicles while at terminals, at truckstops while enroute, and as an assistance in determining the appropriate location of vehicles at origin and destination points.

The 1967 revision calls for the use of one or more of 11 different placards rather than the seven previously employed. It is our strong conviction that the 1967 revision has proved to be satisfactory. Our own awareness of events involving the transportation of hazardous commodities, particularly with respect to accidents and incidents related to their transportation, convinces us there haa been no event with serious consequences since July 1, 1967, in which it is possible to attribute those consequences to

deficiencies in the present placarding system.

In our effort to determine the availability of information which might disclose the effectiveness, or ineffectiveness of the present regulations, we have been told that accident statistics gathered by the Bureau of Motor Carrier Safety, up to this point, do not reflect the precise size of shipments other than that they are either bulk commodities or non-bulk. While private carriers of property are not subject to reporting individual accidents under the present regulations, since 1968 they have been subject to a requirement to file an annual report with respect to accidents involving transportation of hazardous commodities. There is now in effect a hazardous materials incident reporting system which, we are told, will give a better picture of accidents involving hazardous materials provided all carriers properly report such incidents. These requirements will furnish data to indicate the effectiveness of present methods. Far-reaching new proposals should not be undertaken unless and until there are available data which would supoort the necessity for so doing.

In our discussion with representatives of DOT, we were informed that the cost/benefit factor was given careful consideration. We were told that inasmuch as shippers would supply most of the placards under the proposal, the sole coat to carriers will be new placard holders for the vehicles. However, this totally ignores the much more burdensome cost of training and re-training personnel and developing effective training procedures and materials at a point in time when there has barely been enough time for personnel to become thoroughly conversant with the existing requirements. The costs incurred in providing training materials, such aa charts, films, and manuals, and those of paying salaries and wages to affected supervisors, dispatchers, drivers and dock peraonnel, following the 1957 change, demonstrate that the potential cost burden would be great.

It is essential for a placarding system to be understandable to ordinary people, particularly in times of stress such as those which might accompany the over-turn or other involvement of a commercial vehicle in an accident. In order to avoid dangerous mistakes, and to be reasonably sure of effective compliance, regulations providing for a hazard information system should be as simple and as quickly understood by normal carrier employees as possible. In addition, such a system should be easily

those which might accompany the overturn or other involvement of a commercial vehicle in an accident. In order to avoid dangerous mistakes, and to be reasonably sure of effective compliance, regulations providing for a hazard information system should be as simple and as quickly understood by normal carrier employees as possible. In addition, such a system should be easily understood on short notice by fire fighting forces and other emergency response personnel. Experience over a long period of time has indicated that fires and accidents involving hazardous materials which have had major consequences, on several occasions, often occur in small communities or rural areas. It is obvious that the fire fighting and other emergency response personnel available in locations such as these would necessarily be dependent upon an information system as clearly and quickly understandable as possible. The essential information to be conveyed in such situations is best accomplished by the use of plainly understood words, such as are now specified in the placarding requirementa for motor vehicles. The addition of a complex system of numbers not only does not add meaningful information, but actually interferes with the proper execution of responsibilities of carrier personnel. Therefore, we are vigorously opposed to the proposal to utilize placards which require the addition of a hazard information number. The extreme complexities and difficulty of uniform understanding by ordinary people of the table proposed in proposed section 172.502 makes it unworkable and will contribute to failures to comply with the regulations, rather than affording a greater measure of safety.

In short, we believe that the complex system of placarding contemplated in this advance notice will be self-defeating and will tend to interfere with, rather than enhance, aafety in the transportation of these commodities.

We do not object to the requirement for the use of placards on any quantity of those commodities which presently require such use. It is conceivable there may be other goods which should require the display of a placard regardless of quantity. If this is the case, the obvious remedy is for reclassification of those particular items. We seriously object, however, to the great proliferation of placards when a shipment or shipments of a given class aggregates 1,000 pounds or more, while use of the "DANGEROUS" placards is for mixed shipments totaling 1,000 pounds or more. This present requirement appears to us to be more exacting and more effective with respect to the required use of placards than the proposal outlined in proposed section 172.502(b).

The advance notice invites comments on possible locations for attachment of placards to highway vehicles, particularly those vehicles which are frequently used to transport different materials. As to trailers and semi-trailers, the notice proposes a requirement to affix placards to each side and each end of a trailer while loaded, with no optional provision to permit the display of the front placard on the front of the power unit, as is now permitted. The Board notes that the effectiveness of the front placard on a trailer would be reduced when the trailer or semi-trailer is connected to the power unit.

Concerning attachment of placards to highway vehicles, we urge that the regulations not specify such detailed requirements as are set forth in Sections 172.506 and 172.512. Important regulations as these should set forth performance requirements. Excessive detail does not enhance respect for the regulatory requirements in the minds of many people. Furthermore, some federal safety inspectors, in the past, have taken exception to failures to meet detailed requirements which are relatively inconsequential. And finally, such details are wholly incompatible with regulations covered by the severe penalty provisions specified in Title 18, U. S. C., Section 834.

As stated, we vigorously support proposals for improving the regulations when prospective safety results can reasonably be expected. Such regulations must recognize clearly the great differences between high risk and low risk commodities. In order to reduce hazard to life and health, regulations in this area should place greater emphasis on high hazard materials and reduce, or eliminate, the present emphasis on low hazard goods. This can be accomplished by reclassification of materials so that those with greatest risk will be placarded regardless of quantity. Some materials should be so reclassified. Others, with minimal risk, should not be placarded at all. This method of emphasizing cargoes with significant life and health hazards would much more effectively serve the purpose of the regulations, than the methods proposed in the notice.

While the notice states that the present regulations "generally are not addressed to more than one hazard", we are convinced that the safety of the public and of emergency personnel will be more effectively assured by providing a simple notice of the primary, or basic, hazard. The concept of communicating, by a complicated system of related hazards, will hinder, not enhance, understanding by emergency personnel, especially those who become involved only in rare instances.

Our review of the accidents which have had very serious consequences, in terms of loss of life or injuries, over many years, convinces us that the primary hazard characteristic of the cargo was responsible for the consequences in virtually all such events. Except to the extent that warning was dependent on use of the word "DANGEROUS" until July 1, 1967, we do not know of any major case which would have had less severe consequences due to cargo characteristics which were not

disclosed by placard wording. The exception was remedied by the 1967 revision.

As to the statement that the regulations "are not addressed to the different hazard characteristics of a mixed load of hazardous materials," we point out that present section 177.823 (a) (4) requires that any vehicle which is required to be placarded "DANGEROUS" instead of being marked by a specific classification name, shall also display the marking Explosives Class A, Explosives Class B Poison, or Radioactive, as appropriate. Thus, the present requirements do provide for such added notification in those situations where such notification is particularly Fire - Avoid Water" or words of similar meaning, where that warning is appropriate. These warnings, spelled out in clearly understandable words, certainly will serve the purposes of most fire departments and other emergency response personnel, particularly in small communities, to a much more effective degree than the complex system contemplated by this notice.

As to the representation that the present requirements "are onconsistent in their application to the different modes of transport" we point out that this could easily be remedied by extending the provisions of section 177.823, now applicable to highway vehicles, to other modes of transport which do not require such specific identification in classification name with respect to the categories now covered by that section. If it is deemed necessary to require disclosure of any quantity of provision could not be retained without impairment of the present 1,000 pound limitation which applies to highway transport for what are unquestionably sensible and logical reasons.

As we have in the past, we strongly advocate the establishment of a national emergency reporting center in the Department of Transportation. Not only would this be particularly beneficial, but it would seem to be entirely consistent with the intent of Congress in enacting section 302 (a) (2) of the Hazardous Materials Transportation Control Act of 1970, which calls for the establishment of systems to provide technical and other information and advice to the law-enforcement and fire fighting personnel of communities and to carriers and shippers for meeting emergencies connected with the transportation of hazardous materials.

The fact that the Manufacturing Chemists Association has established the Chemical Transportation Emergency Center, and the extent to which that effort has been of valuable assistance within is first year of operation, indicate clearly the desirability and usefulness of such a center adequately equipped with competent personnel. Such a central reporting center would be useful to fire fighting people and motor carrier personnel when confronted with emergency situations in small communitias and in rural areas. The establishment of such a center within the Department of Transportation would go far beyond the communications effort now contemplated by the Board in its advance notice. It would be able to furnish practical and immediate assistance, such as specific information about the handling of hazards associated with specific commodities involved in a fire or spillage. It should

be manned by personnel who would have available expert information in handling of any aspect of a transportation incident to assure that incidental factors, such as handling of a vehicle by a crane crew, would not cause the situation to deteriorate. It ahould have the capability of furnishing a team of experts to go to a scene, when needed, to assist in the handling of extremely hazardous situations. We sincerely urge that this matter be given careful consideration as a meaningful alternative to the complex situation proposed in the advance notice.

We further urge that measures be initiated, as soon as possible, to simplify the existing regulations, rather than develop proposals which so inordinately add to their complexity. The 1972 edition of the Code of Federal Regulations which deals with transportation of hazardous materials is a very voluminous and complex document. Title 49 of the Code, Parts 100 to 199, requires nearly 900 pages of printed material. The regulatory authorities, including the Hazardous Materials Regulations Board and the Bureau of Motor Carrier Safety in the Federal Highway Administration, should not limit their concerns to the quantity, variety and complexity of the materials being transported. They should also be concerned that there is concurrently a remarkable increase in the quantity, variety and complexity of the regulations governing the transportation of such materials. While safety in transportation is the objective of these regulations, the objective is obscured and its realization is severely limited by the inability of transportation employees to know and understand the regulations and by the difficulty of carrier managements to comply with the multiplicity of these requirements. When regulatory requirements become so extremely complex and numerous, it is inevitable that errors will occur with consequences that can be extremely serious, such as communicating inaccurate informstion to emergency response personnel. It is extremly important that the regulatory scheme be simplified. Those who develop regulatory proposals must consider both the educational level and the motivation of those who are required to meet the regulatory requirements. The proposal set forth in the advance notice is written at the educational level of persons in DOT who are experts in their knowledge of various materials and have made an in-depth study of concepts which have been expressed only in sophisticated manner. The regulations should be written on a more practical level for quicker and easier comprehension by truck drivers, dispatchers, freight handlers as well as by fire fighters, many of whom are dependent upon the essiest comprehended communication such as indicated by plainly legible words.

In summary, we urge (1) that, for the reasons stated above, the Board should not proceed further with the complex system set out in the advance notice; (2) that if there are cases in which the significant hazard characteristics of materials are not adequately communicated, this be remedied by reclassification of those commodities, and thus result in plainly worded information within the present system; and (3) that the Board move as expeditiously as possible to effectuate the recommended improvements set forth above.

EXPLOSIVE YIELD CRITERIA

Ralph E. Reisler

Ballistic Research Laboratories

This paper presents some of the results of an experimental study of the blast parameters produced from cylindrical charges detonated on the surface of the ground. Conducted under the sponsorship of the DDESB, information was sought which could be used in the determination of the explosive yield of military ordnance systems and suhsystems. Most explosive ordnance items can best be described by cylindrical or conical geometries or a combination thereof.

A wealth of blast data is available on hemispherical and spherical charges and some data on cylindrical charges detonated in the free air, but little information on cylinders fired on the ground surface. Hence an experimental program was designed to gather data on the blast from cylindrical charges fired on or near the ground oriented with the axis parallel and oblique to the ground surface.

The experimental program is delineated in Table 1. Cylindrical explosives having length to diameter ratio's of 3,6 and 12 were selected as representative of various ordnance items. Three rounds for each geometry were fired with the charge in a vertical position and with the initiation from the top. Then, the point of initiation was changed to the base of the cylinder and three rounds each were fired. In the next group, charges were placed in a horizontal position on the ground and detonated from one end; two rounds each were fired with the charge oriented at angles of 0, 45, 90, 135 and 180 degrees to the instrument line for each L to D ratio. To complete the program, each of the 3 geometries were fired in a position 45 degrees to the ground surface with end initiation away from the ground for 3 rounds of each size

All charges as shown in Table 2 had a nominal weight of 8 pounds, were bare Pentolite, and had length dimensions from 11.5" to 29" and diameters from 2.4" to 3.8".

Firings were made on a sand test bed. Restoration of the ground zero area was carried out with compacted sand after each event. Shown in Figure 1 is the field layout. The geometric center or a projection thereof was used as the ground zero point. Eight blast gages were installed along a line extending from 6 feet to 53 feet. Two additional gages were located at off angles, one at 45° and one at 90° equal to sta. 6 at 17 feet. The pressure transducers were Susquehanna Instrument Company Model ST-2 piezoelectric sensing elements having a natural frequency of 250 KHz. Signals were recorded on a Honeywell Model 7600 tape recorder having a frequency bandpass of 0-80 KHz. The data was reduced with the aid of analog to digital conversion equipment together with the BRL computer. Arrival time, overpressure, positive duration and overpressure impulse were obtained from the more than 500 records.

For the purposes of this paper, we have elected to concentrate on the data from the charges positioned horizontally on the ground. A final report will cover the entire program. Figure 2 summarizes the data in an iso-overpressure chart for the L to D of 3. Picture the charge in the center with the initiation point at the end in line with the 0° line. Keeping the charge fixed and moving clockwise we have the instrument line at 0, 45, 90, 135 and 180 degrees to the ground zero point (in actual practice the instrument positions were fixed and the charges rotated). The maximum overpressure is higher along the 90° line out to the 10 psi level than along the other lines. From 10 psi (approximately 22 feet) out to the greater distances, the 45 and 135 degree positions show higher overpressures. Looking at the 0° versus the 180° positions (the detonator close to the instrument line versus the detonator away from the line) we see the 180° line measuring on the whole slightly higher pressures than the 0° line.

When comparing the maximum overpressure along the five blast lines with the hemispherical charge data, the distance at which 10 psi occurs is somewhat the same for the 45, 90, and 135 degree line but different from the 0 and 180° line. As one preceeds toward GZ from 10 psi, the 90° line from the cylinder is clearly greater than the hemisphere. At the other angles, the trends are mixed. A cross-over appears in the region of 10 - 30 psi on the 45 and 135° lines. On these same lines at 60 and 100 psi, the cylinder is less than the hemisphere. On the 0 and 180° lines at these same pressures, the 0° line is nearly equal to the hemisphere but the 180° line is greater than the hemisphere. Proceeding away from the 10 psi level, the 90° cylinder line is less than the hemisphere while the other angles tend to yield pressures greater than the hemisphere.

These same patterns exist with the spherical data. Note the variations between the hemispherical and spherical data.

Looking at an L to D of 6 in Figure 3, we see the same general pattern repeated. It is also the same in relation to the hemisphere and sphere.

Moving to the L to D of 12, Figure 4, we see a slight change in the pattern. The 10 psi level at the 0 and 180 degree lines occurs at a distance greater than 20 feet in contrast to 15 feet for the previous L to D's. In relation to the hemispherical and spherical data, the three are approximately equal at 10 psi.

The pressure versus time histories from the 0° line presented in Figure 5 for the L to D of 12 and Figure 6 for an L to D of 3 show the complex wave patterns generated from the ends of the charge. On the L to D of 12 a secondary wave is seen at 10.5 feet which continues through to 17 feet. Shortly thereafter the secondary wave disappears. In Figure 6 with an L to D of 3 we have a similar occurrence taking place. This time the disturbance created by the secondary wave has not disappeared until shortly after 30 feet. In all cases the maximum pressure values were used in plotting pressure versus distance curves.

A study was conducted by Denver Research Institute with cylindrical charges fired in free air in which they documented the wave development off the ends of

the charge using photographic and pressure gage techniques, Reference 1. Presented in Figure 7 is a schematic of this wave development. Due to the end configuration and the presence of corners, three waves are generated: one to the side labeled side wave, one off the end labeled end wave and a third off the corner labeled bridge wave. Reflections occur as a result of the interaction of these waves. DRI further confirmed the fact that the corners are responsible for the formation of both the bridge and reflected waves by conducting a special series of experiments using a hemispherical end cap. We feel that this same phenonema is occurring with the charges on the ground. An explanation as to why some trailing wave fronts tend to heal by overtaking and merging with the primary front while others tend to recede into the wave is discussed in their report. Briefly, if the second front moves through a medium having conditions higher than ambient, the second front overtakes and merges with the primary front; if the medium through which the trailing front travels differs very little from the ambient, the secondary wave front recedes into the main blast wave.

Iso-overpressure impulse charts are shown in Figures 8 through 10. The same trends seen in the overpressure curves are evident in the impulse curves i.e. higher values out the 90° line to a point, in this case 15 psi-msec, than the other directions; beyond 15 psi-msec, the 90° line falls below the 45 and 135 degree lines. The 0° line tends toward slightly higher impulse values than the 180° line. In comparison with hemispherical and spherical data, the impulse is less generally than that generated by the hemisphere or the sphere.

Shown in Figure 11 are pressure time history comparisons of a sphere and a cylinder of L to D of 12 fired at 90°. Note the higher pressures and shorter durations of the cylinder in relation to the sphere at 12.5 and 17 feet. This pattern changes at the lower pressures (30 and 53 feet) where the cylinder pressure and duration are both less than the sphere.

In conclusion, we have observed from 8 pound Pentolite cylinders fired horizontally on the ground a pressure field off the 90° side greater than off other angles excepting at low pressures. This may be attrihuted to the so-called presented area effect as outlined by Evans and Parks, Reference 2. This effect infers that the greater the presented area of the explosive in a given direction, the higher the resultant peak overprssure obtained in that direction.

In relation to hemispheres, higher pressures from the 10 psi region and forward are obtained from cylinders in the 90° plane; the impulse, however, from cylinders is considerably less. Differences in wave form decays were observed.

Additional work is required before the validity of scaling can be determined

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2. Evans, R. W. and Parks, D. K. The Development of Equations for the Prediction of Explosive Effectiveness, University of Denver, Denver Research Institute, 1 February 1959 Conf.

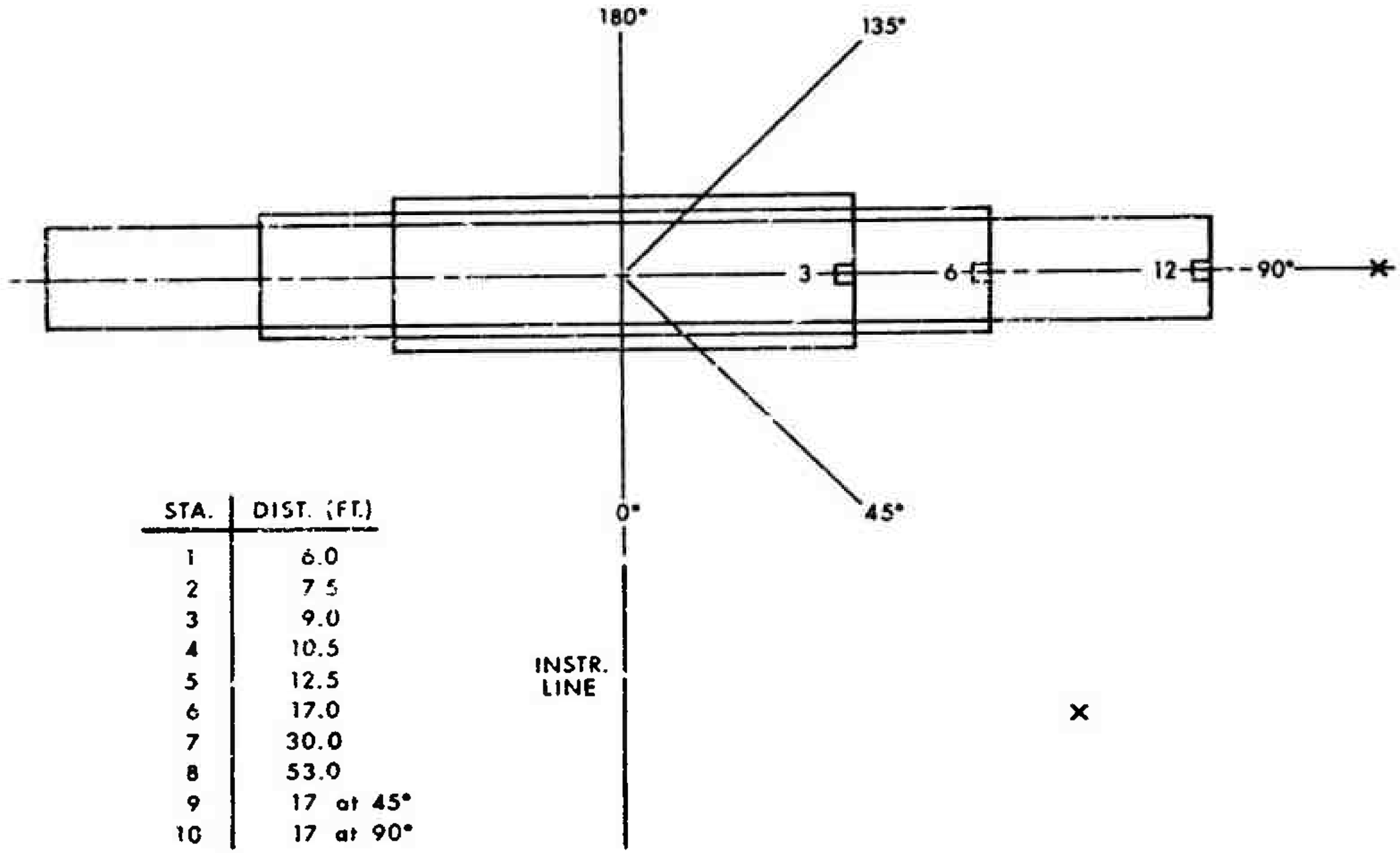
L/D	ORIENTATION	INITIATION	ϕ *	NO. RNDS.
3, 6, 12	VERTICAL (90°)	END, TOP	0°	9
3, 6, 12	VERTICAL (90°)	END, BOTTOM	0°	9
3, 6, 12	HORIZONTAL (0°)	END	0°, 45° 90°, 135°, 180°	30
3, 6, 12	45°	END	0°	9

* ANGLE BETWEEN INSTRUMENT LINE & CNTR OR CNTR LINE OF CHARGE.

Table 1 Firing Program.

L/D	AVG WT (LBS)	LENGTH (IN.)	DIAMETER (IN.)
3	7.73	11.54	3.846
6	8.13	18.33	3.055
12	7.86	29.10	2.425

Table 2 Pentolite Charge Specifications.



STA.	DIST. (FT.)
1	6.0
2	7.5
3	9.0
4	10.5
5	12.5
6	17.0
7	30.0
8	53.0
9	17 at 45°
10	17 at 90°

Figure 1. Field Layout.

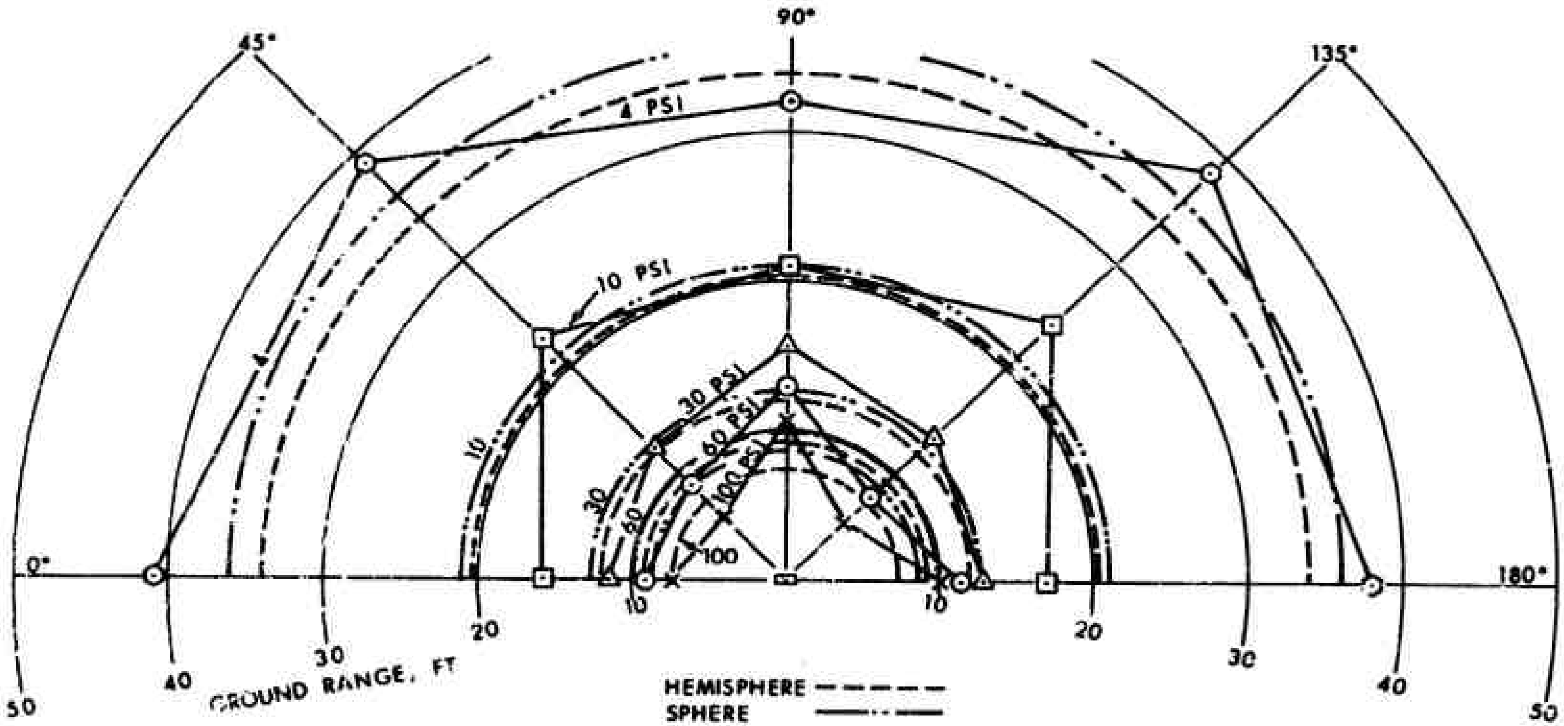


Figure 2 Iso-Overpressure Chart, L/D-3.

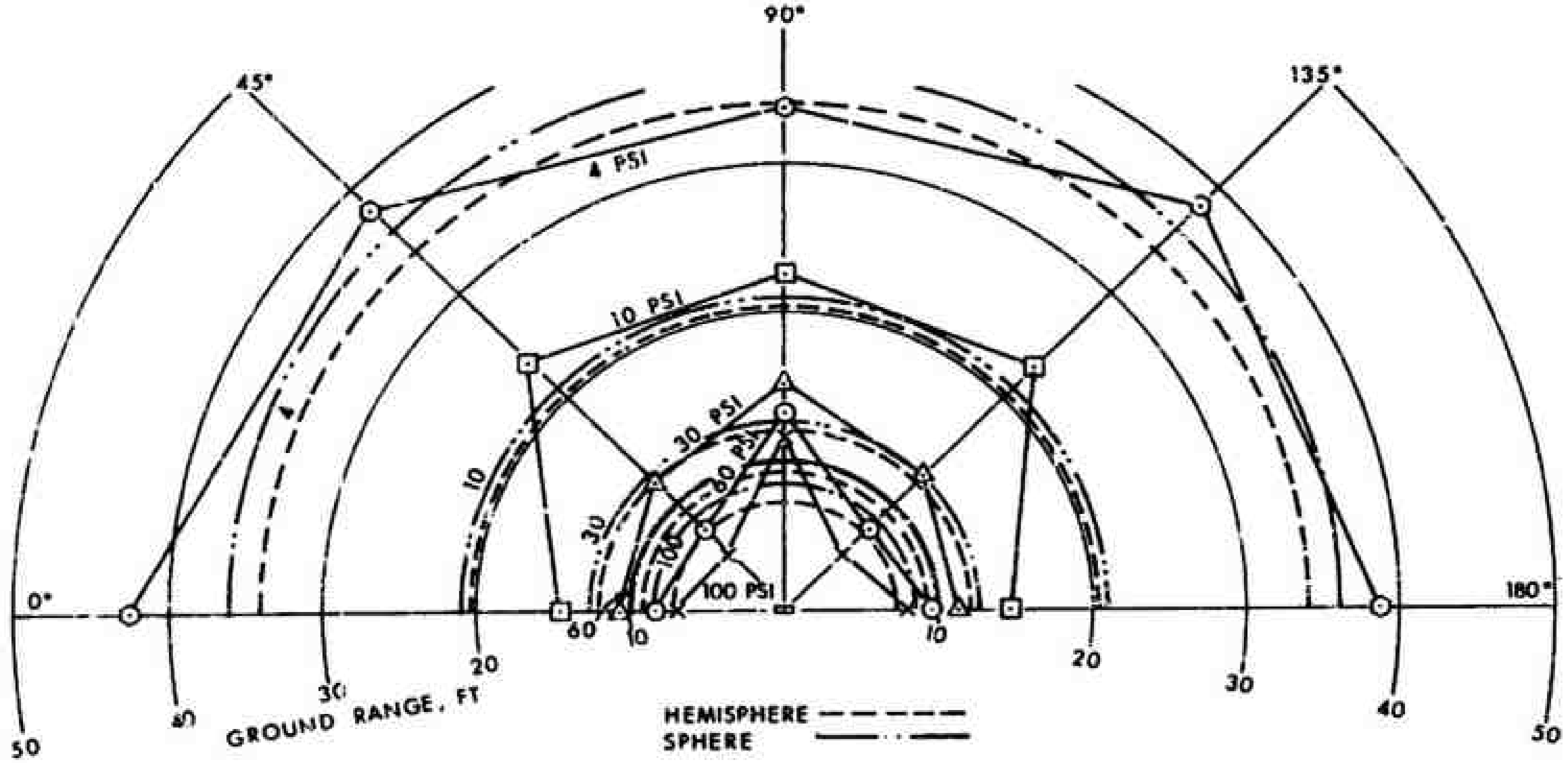


Figure 3 Iso-Overpressure Chart, L/D-6.

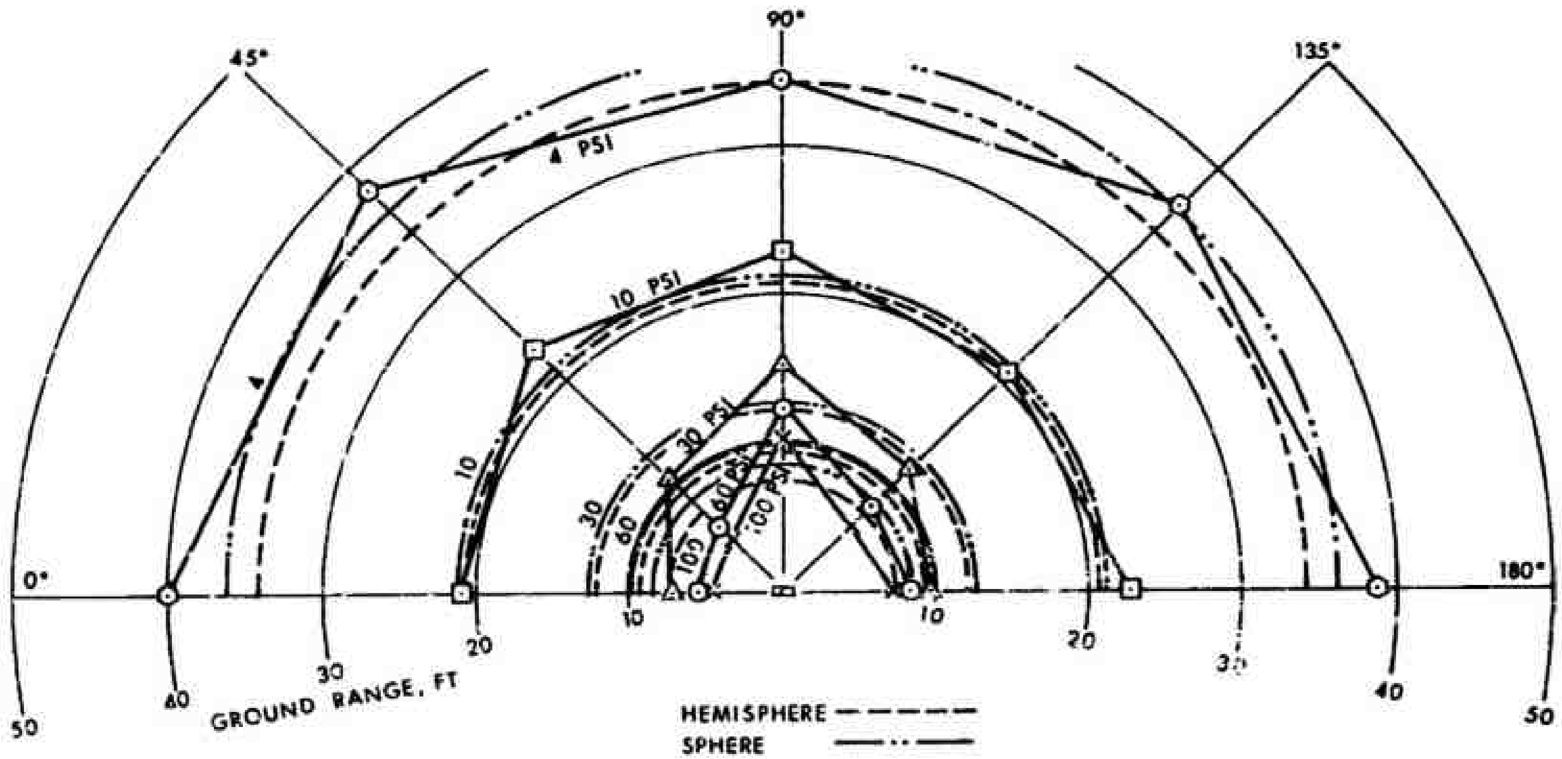


Figure 4 Iso-Overpressure Chart, L/D-12.

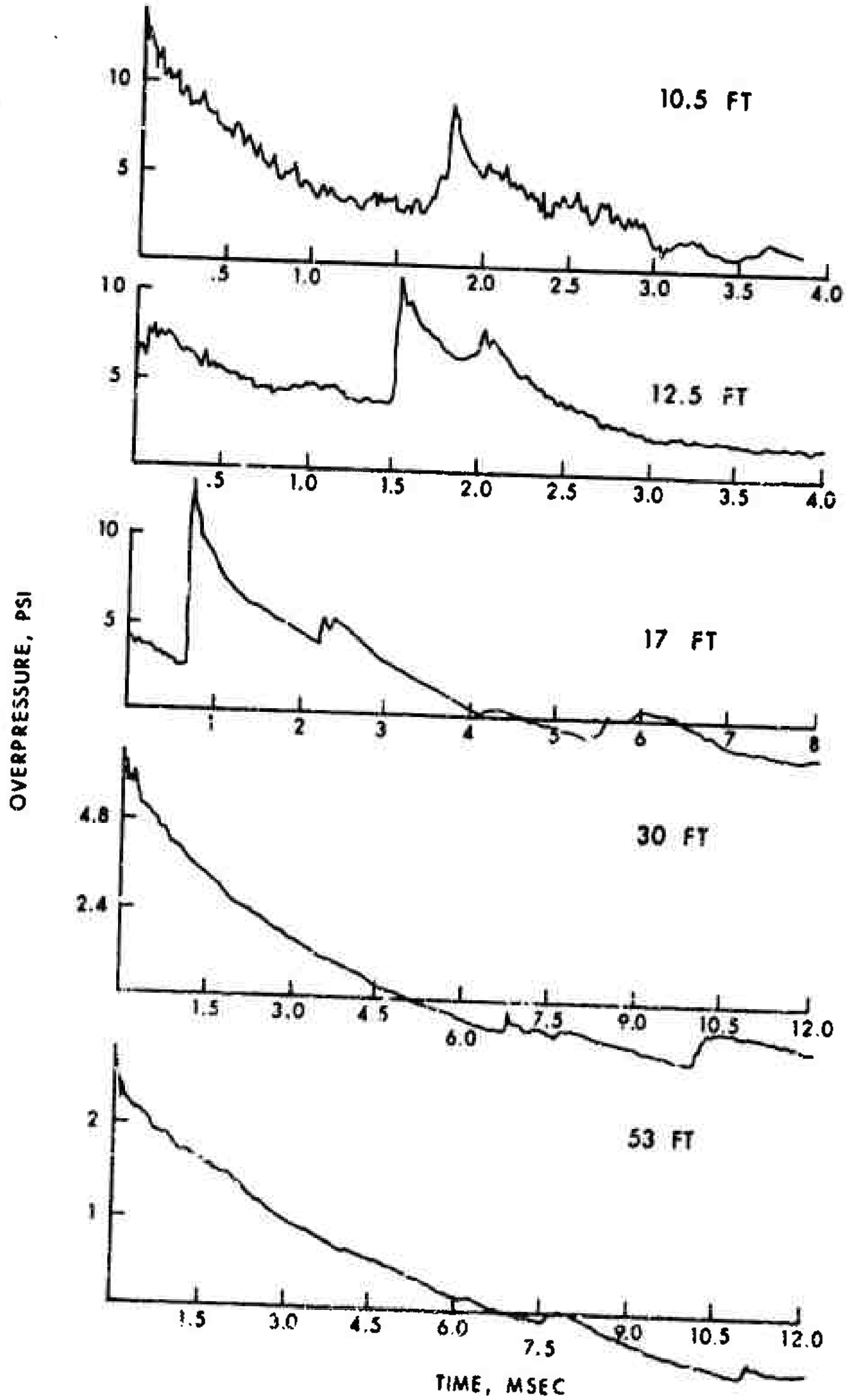


Figure 5 Pressure Time Records, 0 deg. Line, L/D-12.

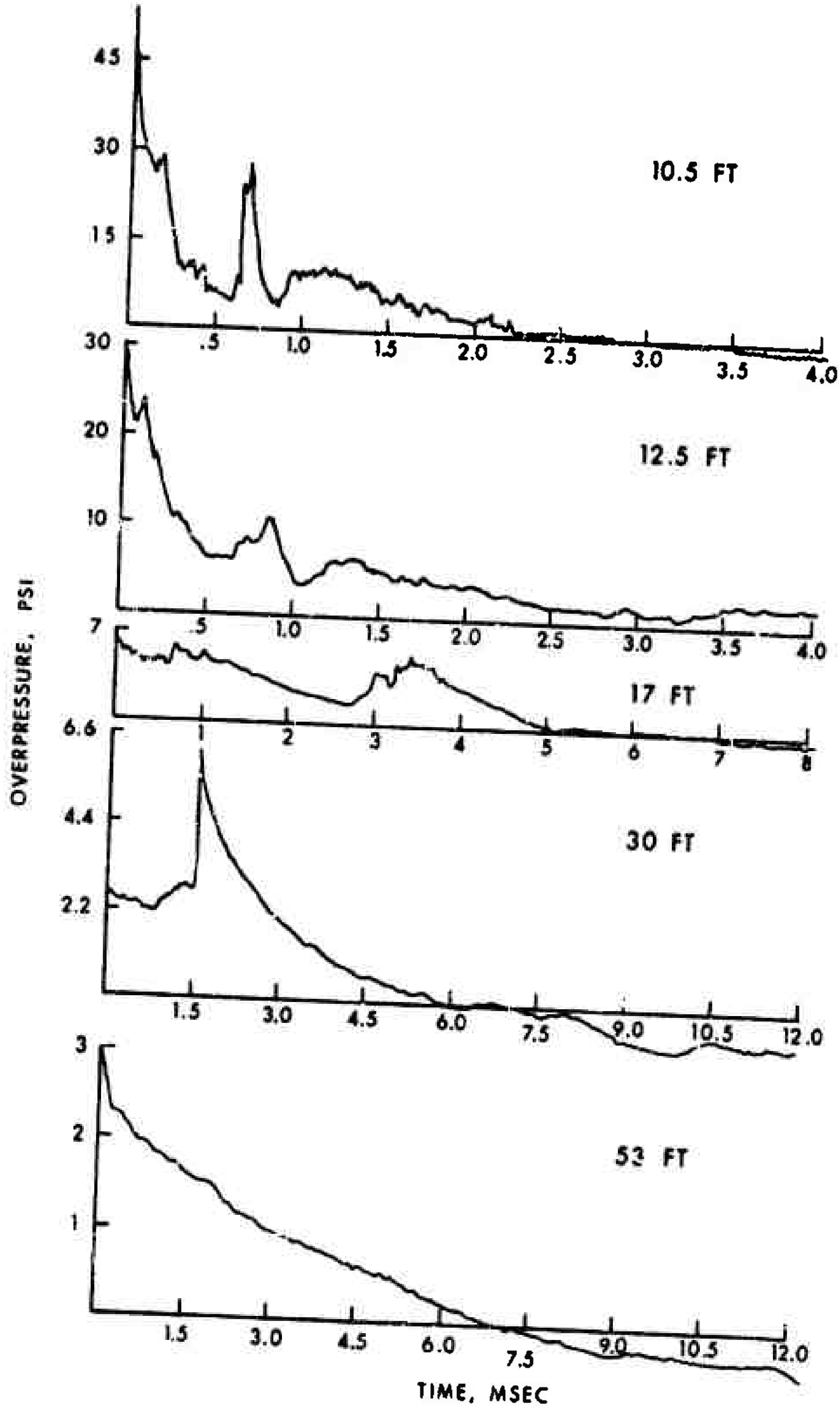


Figure 6   Pressure Time Records, 0 deg. Line, L/D-3.

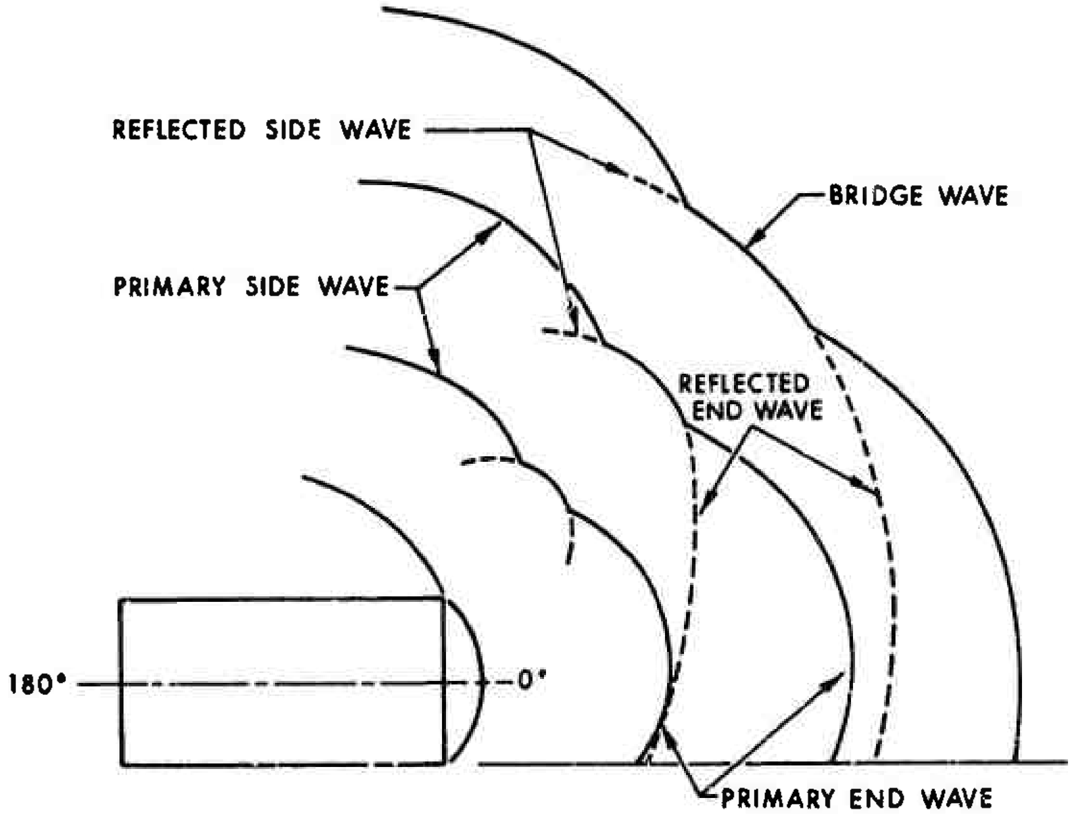


Figure 7 Schematic of Wave Development.

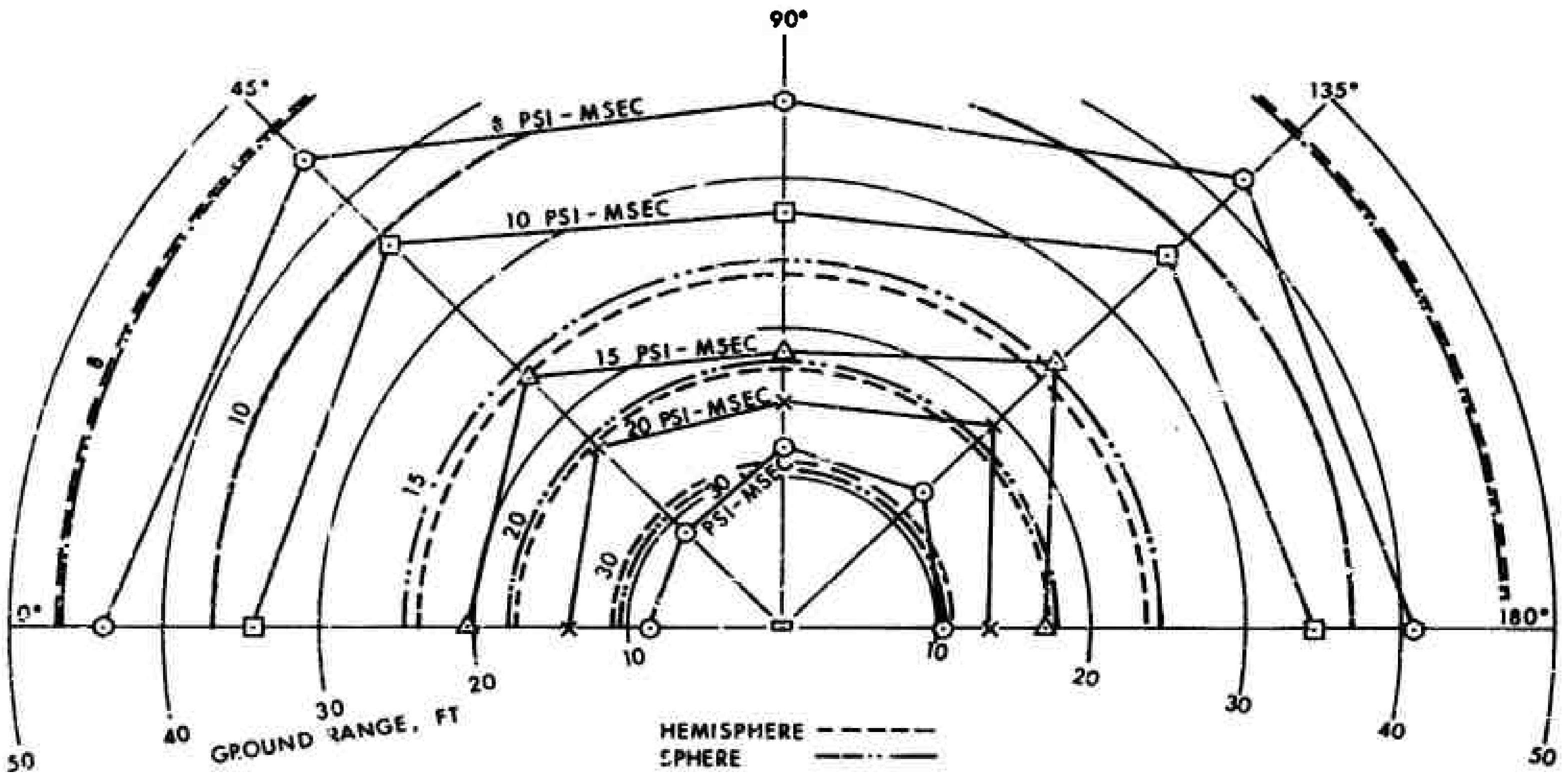


Figure 8 Iso-Overpressure Impulse Chart, L/D-3.

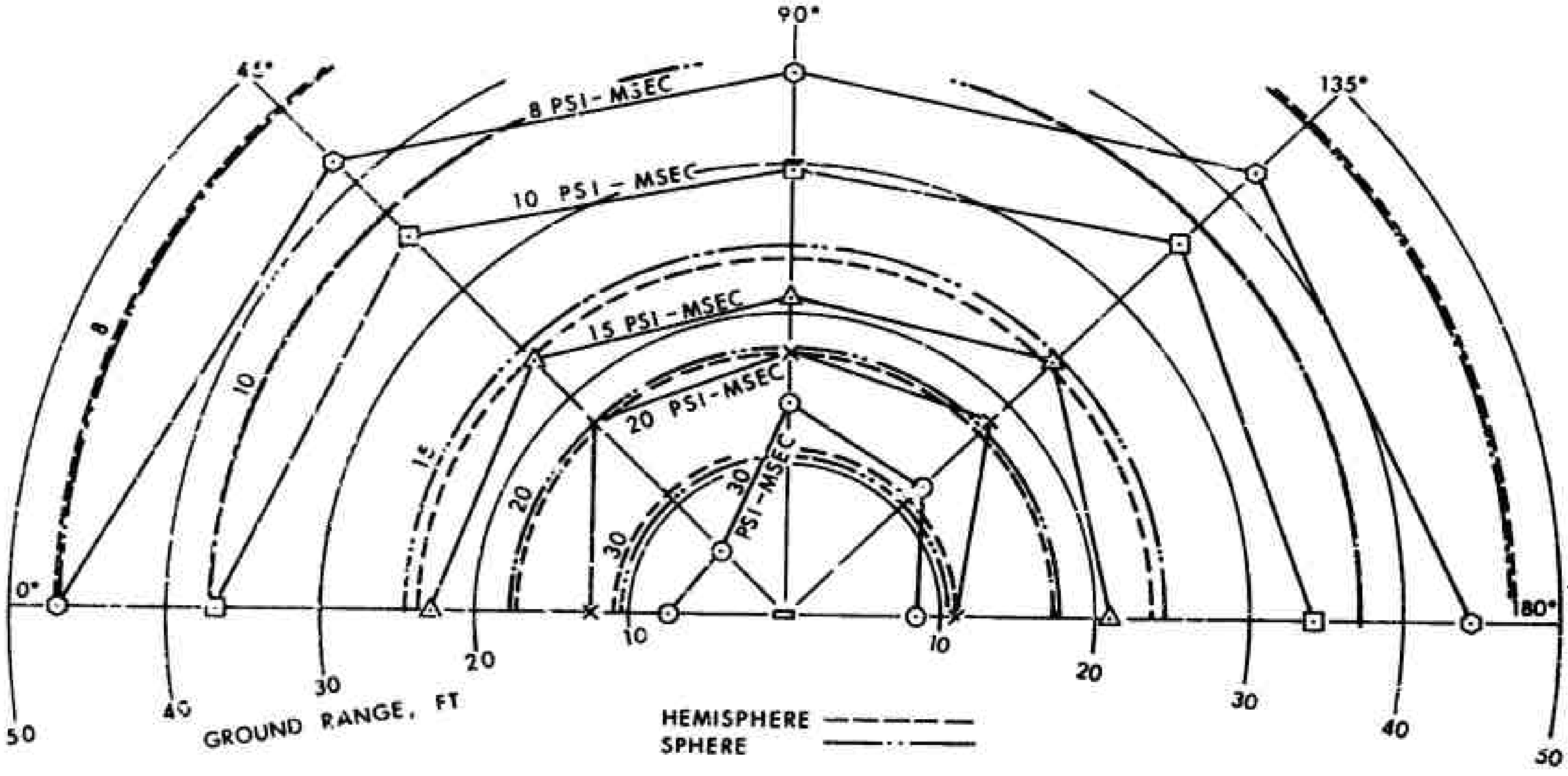


Figure 9 Iso-Overpressure Impulse Chart, L/D-6.

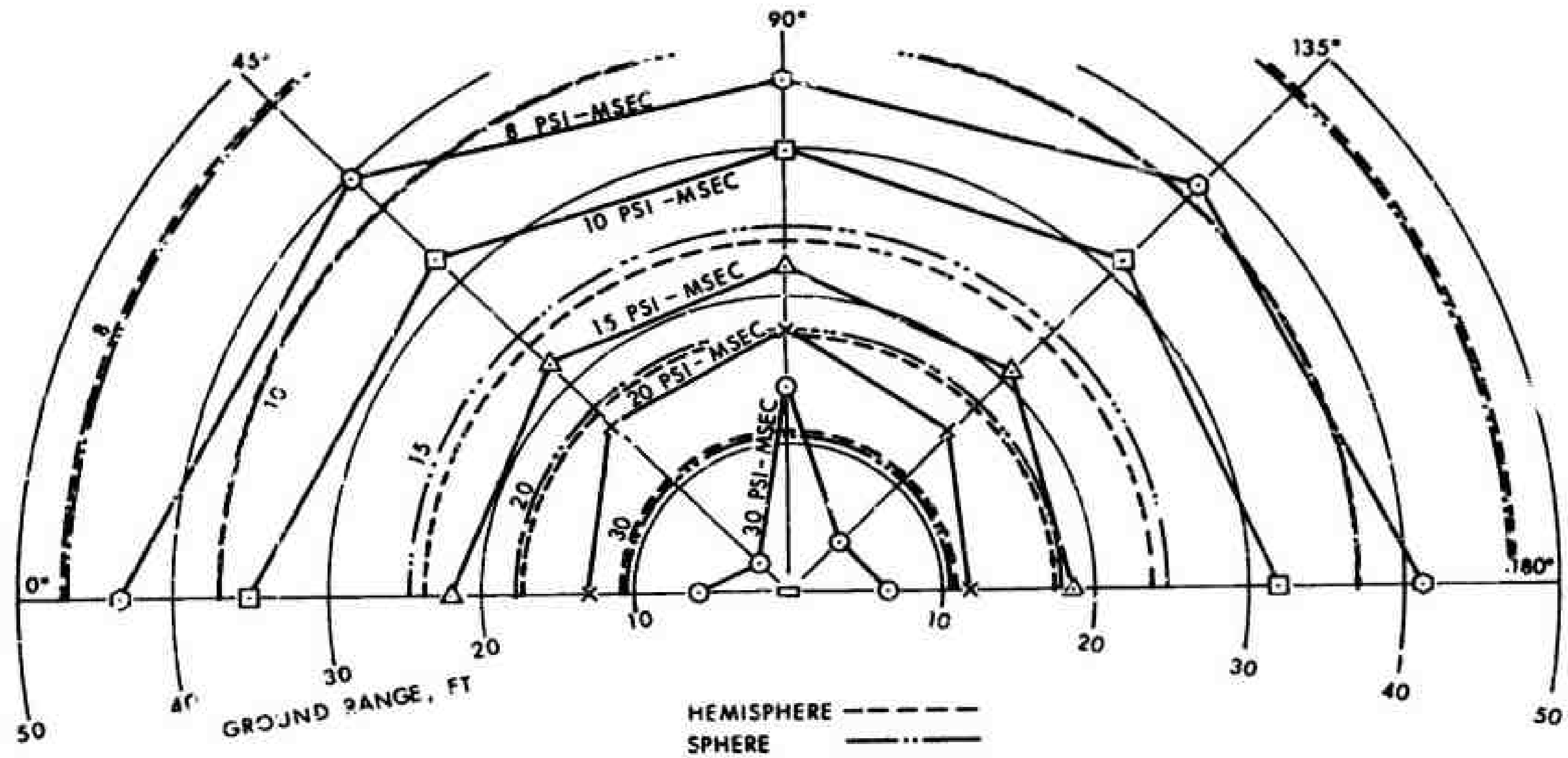


Figure 10 Iso-Overpressure Impulse Chart, L/D-12

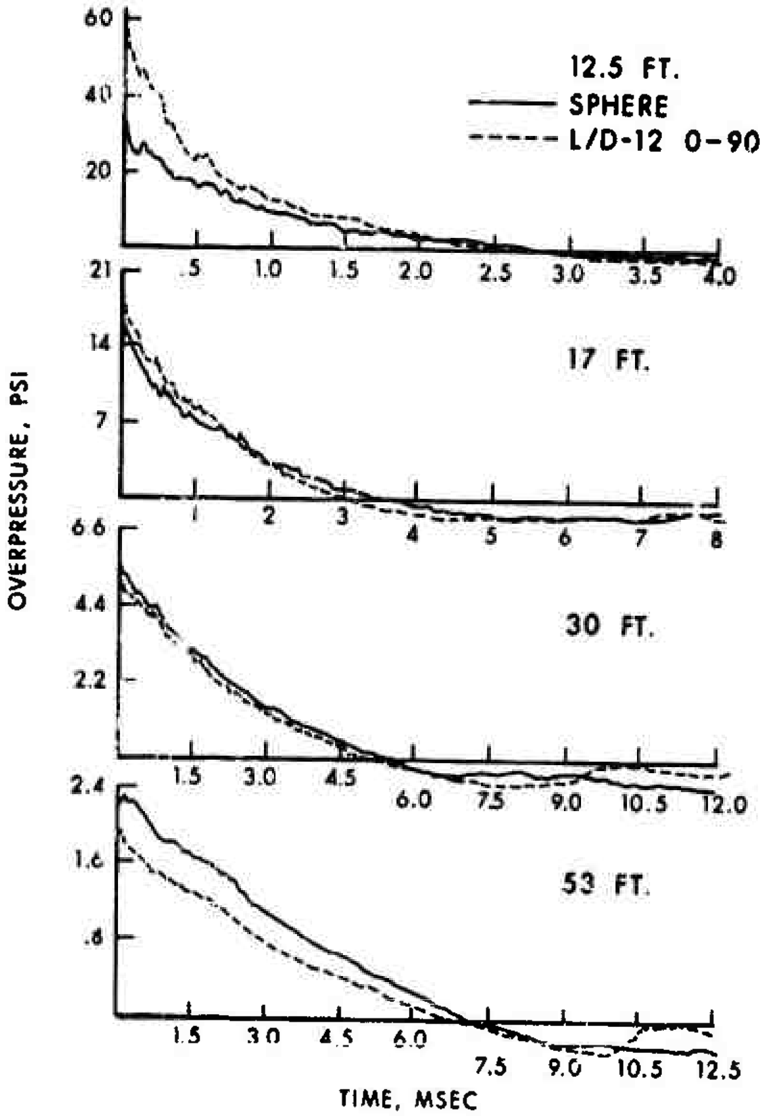


Figure 11 Comparison of Pressure Time Records, Sphere and Cylinder.

TNT EQUIVALENCY STUDIES

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SUMMARY

TNT Equivalency studies are being carried out at IITRI under the technical direction of the Manufacturing Technology Directorate of Picatinny Arsenal in support of the Army's Plant Modernization Program. The purpose of the TNT equivalency investigations is to determine maximum explosive output in terms of blast overpressure and impulse. The materials being considered are explosives, propellants, and pyrotechnics at each stage of their life cycle, ranging from the in-process forms of the materials to the finished items in their shipping configurations. The cost of new manufacturing facilities could be reduced if building construction and quantity-distance siting is based on a realistic evaluation of the actual airblast parameters of the in-process materials.

The major emphasis of this paper is on the application of TNT equivalency test results for black powder to the design of a new black powder manufacturing facility. Based on these test results, significantly lower values of TNT equivalency than those currently used should apply to the design.

Results of evaluations of in-process N-5 propellant and the packaged M1 propelling charge, single items and pallets, are discussed. Currently under investigation are M8 propellant and in-process forms of nitroguanidine. Three pyrotechnic compositions will be evaluated in the near future. Plans are underway for additional evaluations of the airblast parameters for a number of in-process explosives, propellants, and pyrotechnics, as well as finished items.

The end product of this work will be a handbook or supplement to TM5-1300, "Structures to Resist the Effects of Accidental Explosions." This supplement will outline the procedures to be used for testing, measuring the blast parameters, and for calculating TNT equivalency. The procedures will apply to any hazardous material in any stage of manufacturing. A compilation of all existing data on TNT equivalency will be included in the handbook, and provisions will be made for ease in updating the data bank.

INTRODUCTION

Airblast parameters were determined for a number of in-process propellant and explosive materials, as well as finished

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items. The measured airblast overpressure and impulse values are compared with that produced by TNT in order to determine the TNT equivalencies of the materials. Data is presented in this paper for Black Powder[1], N-5 propellant[2] in its in-process slurry and paste forms, and the M1 propelling charge[3] in its shipping container.

In these investigations, we are concerned with determining the maximum blast output that the propellant or explosives are capable of achieving. We are not concerned with the sensitivity of these materials, which is related to the ease of initiation, nor are we concerned with the likelihood or probability of an initiation occuring. The airblast data was obtained for application to the design procedures given in TM5-1300[4], "Structures to Resist the Effects of Accidental Explosions," for the purposes of construction or new explosive manufacturing facilities and the quantity-distance siting of these facilities.

TEST PARAMETERS

Measurements of airblast overpressure and impulse were made at 6 gage locations along a single blast line. The gage locations were spaced at selected scaled distances ranging from approximately 2 to 20 ft/lb$^{1/3}$. The pressure transducers were installed flush with the top surface of a concrete slab in mechanically-isolated steel plates. The concrete slab is 75 ft. long and 10 ft. wide. These steel plates cover a channel in which gage leads are placed. The test item is placed at one end of the slab and level with the slab. Fastax motion pictures were taken of all tests.

Factors that affect the explosives' output, as measured by their airblast parameters, are the quantity of material being tested, the charge geometry, confinement, and booster weight. Experiments were designed to evaluate these effects. Charge geometries and confinement levels, in general, simulated the in-process conditions or, in the case of the M1 propelling charge, their shipping configurations.

The materials evaluated, which can be classed as "marginal explosives," were initiated with boosters whose detonation pressures were higher than the detonation pressure of the test material. Both conical and cylindrical boosters were evaluated. Since conical boosters have a high initiating effect for their weight[5], for boosters placed externally with the end surface in contact with the charge; when the same weight booster and surface area in contact with the explosive charge was maintained, the same airblast parameters were achieved. Hence, we had flexibility in the placement of the boosters, as shown in Figure 1, depending upon the problems encountered with each test configuration. C4 explosive was used as the booster for most of the tests. The only exceptions were a few tests on black powder

where 0.54 lb. of 9404PBX was used as the booster explosive, and those tests that were squib-initiated or initiated with 11 gms (.024 lb.) tetryl.

Although Figure 1 shows black powder in a cardboard container, various levels of confinement were evaluated for their effects on output. The levels of confinement in the order of increasing confinement were:

- The material is in a cardboard container supported on wood pedestals, so that the container is placed above the ground a few inches;
- The cardboard container is placed on the bare ground, which is a sandy soil;
- The cardboard container is placed on a thick steel plate flush with the ground;
- The explosive sample is completely confined in a steel container, placed on a steel base plate.

BLACK POWDER TEST RESULTS

Representative test results in terms of peak pressure and scaled impulse are shown in Figure 2 for 25-lb. charges of black powder initiated by boosters ranging in weight from 0.024 lb. to 1 lb. Each test is generally repeated three times. The scaled distances and scaled impulses shown in Figure 2 are based on the black powder charge weight alone, and have not been adjusted to take into account the weight of the booster explosive.

The test data in terms of peak pressure and impulse are compared with data on hemispherical surface bursts of TNT in order to determine TNT equivalencies. The data on TNT is obtained from that available in the literature and a large number of tests carried out at IITRI. The TNT reference curves are shown in Figure 3. The TNT pressure/impulse equivalencies are obtained by determining the weight of TNT that would produce the same peak pressure (or positive impulse) at the same distance as a given black powder charge. It is the ratio of this weight of TNT to the weight of black powder that defines the TNT equivalencies. Details regarding the computational procedure are given in the reports referenced at the end of this paper. For all the TNT equivalency curves, scaled quantities, i.e., impulse and distance, are based on total charge weight, which includes a correction that is made to account for the booster explosive weight.

Notation

In Figure 4, as in other figures in this paper, the notation used to describe a test such as CON-9,10 (BP 140, 0.024) is defined as follows. CON-9,10 represents the results of two tests,

Shot Numbers 9 and 10, of the series of tests in which the samples were confined in steel. These tests were on black powder (BP) weighing 140 lbs. and initiated with a 0.024-lb. tetryl pellet. Thus, the first letters and numbers designate the shot numbers, while the information in parenthesis refers to the type of explosive tested, its weight, and the booster weight. JM stands for jet-milled material, an in-process form of black powder. SP stands for steel plate, which is indicated when an unconfined charge is placed on a steel witness plate, and SQ stands for squib.

Effects of Charge Weight

Figures 4 and 5 show the effect of charge weight on TNT pressure and impulse equivalencies for black powder confined in steel containers. The confined charges were initiated with either a squib or 0.024-lb. tetryl pellet.

The TNT pressure equivalency for black powder reaches a maximum value at a scaled distance of between 7 and 10 ft/lb$^{1/3}$ for both confined and unconfined conditions. On the other hand, the impulse equivalencies are essentially constant with distance. This is related to the fact that the pressure-distance curve for TNT is concave, whereas the pressure-distance curve for black powder is convex. The scaled impulse-distance curves for TNT and black powder are nearly parallel, which accounts for the fact that impulse equivalencies do not vary significantly with distance.

Effects of Confinement and Booster Weight

Figures 6 and 7 are summaries of test results which show the effects of confinement and booster weight for 25-lb. black powder charges on their TNT pressure and impulse equivalencies. These figures, as well as data shown in Figures 8 and 9, indicate that the level of confinement is more important than booster weight in influencing the airblast parameters. Small increases in the degree of confinement substantially increase the TNT equivalency. The dashed lines in Figures 6 and 7 are for tests using a 0.54-lb. 9404PBX booster. The black powder output was greater when 9404PBX boosters were used than when C4 boosters of approximately the same weight were used. Thus, not only booster weight but the detonation pressure of the booster can affect the extent of initiation of a marginal explosive like black powder. As was cited in the beginning of this paper, the contribution of the booster explosive is taken into account in arriving at scaled quantities.

Summary of Black Powder Tests

The majority of the data obtained on black powder are summarized in terms of TNT pressure and impulse equivalency as a function of booster weight for selected scaled distances, and are

shown in Figures 8 and 9, for $\lambda = 2\ ft/lb^{1/3}$ and $\lambda = 10\ ft/lb^{1/3}$, respectively. All the data for unconfined tests fall within the envelopes shown. For the purposes of this figure, unconfined tests refer to all tests where the material was in a cardboard container, even though, in some of the tests, the container was placed on a steel base plate, which definitely caused an increase in blast output when compared with tests where the cardboard container was placed on sandy soil. Detailed data on these many effects are found in the two-volume report issued on black powder (Reference 1). For quantity-distance siting and building construction, the outer envelope of all the data points, as shown in Figures 8 and 9, is probably the most useful, since in a manufacturing facility a range of weights are used in various pieces of equipment and a wide range of confinement levels exist.

In summary, the following can be cited:

- Confinement effects are significant. Small increases in the degree of confinement substantially increase the TNT equivalency of black powder.
- Pressure and impulse equivalency increases with increase in both black powder charge weight and booster weight. The maximum values obtained were 24 percent for pressure equivalency at a scaled distance of 7 and 43 percent for impulse equivalency at a scaled distance of 2.
- When all data are compared on the basis of equal ratio of booster weight to black powder weight, the TNT equivalencies for 75-and-150-lb. charges are essentially equal, whereas 25-lb. charges have lower equivalency values.
- Pressure equivalency increases with scaled distance, reaching a maximum value at a scaled distance of between 7 and 10 $ft/lb^{1/3}$ and then decreases.
- Impulse equivalency does not vary appreciably with scaled distance, but it is always greater than the pressure equivalency.

M1 PROPELLING CHARGE TEST RESULTS

TNT equivalency determinations were made on the M1 propelling charge in its shipping container. Single charges, small clusters, and full pallets were tested. The charge and booster configuration is shown in Figure 10 for the case when the booster was placed inside the canister. Conical boosters of C4 explosive were placed both inside and outside the can. When placed on the outside, tests were carried out for both base plate and side-wall location of the booster. Thirty-gram cylindrical tetryl boosters were also used to initiate the charge, in accordance with TB 700-2(6).

The cluster and pallet tests consisted of 5, 15, and 25 canister configurations, as shown in Figure 11. Also tested was a full pallet which consisted of two stacks of 25 units in each stack, also shown in Figure 11. In all cases only one item was initiated, and this is indicated by the dashed marks on the center canister in the second row of Figure 11.

Figure 12 shows the peak pressure and scaled impulse data for tests of single M1 charges placed in a vertical orientation for various booster weights ranging from 0.024 lb. to 2 lbs. The scaled quantities (distance and impulse) are based on the total charge weight where a correction has been made to take into account the weight of the booster explosive. As expected, as booster weight increases, the pressure and impulse increases.

The pressure and impulse data for the M1 propelling charge is compared with that produced by TNT in order to obtain the TNT equivalency of the M1 charge. TNT equivalency is defined as the ratio of the weight of TNT to the weight of the M1 charge which would produce the same overpressure (or impulse) at the same distance. Data on TNT equivalencies for pressure and impulse were computed for each test. A summary of this data for impulse equivalency is shown in Figure 13 for selected scaled distances ranging from 4 to 20 $ft/lb^{1/3}$. The abscissa is the ratio of booster weight to charge weight in percent. This shows that, after the booster weight reaches about 5 percent of the charge weight, an increase in booster weight will not result in an increase in the TNT equivalency of the material. Hence, one can be confident that the maximum blast output for M1 propelling charge has been achieved.

The maximum TNT impulse equivalency occurs at a scaled distance $\lambda \approx 4\ ft/lb^{1/3}$ and is greater than 100 percent (Figure 13). The reason for this high value is that the M1 charge in its canister, which has an aspect ratio of six, is compared to a hemispherical charge of TNT rather than to a TNT charge of the same geometry. If it were compared to a TNT charge of the same geometry ($L/D = 6$), then the maximum TNT equivalency would be much lower. However, the reason for computing TNT equivalency with respect to a hemispherical TNT charge is that the application of this data is to provide correction factors to the design procedures of TM5-1300. In this design manual, explosion effects are computed with respect to hemispherical TNT charges as the reference explosive.

A summary of TNT pressure and impulse data obtained in partial pallets of the M1 charge are shown in Figure 14. In all cases, the booster weighed 0.5 lb. The effects of locating the booster on the inside of the canister, on the outside of the side walls, and outside on the base of the can are shown in this figure.

As can be seen in Figure 14, the output from clusters of canisters is considerably less than that from single cans. One should expect a maximum pressure and impulse equivalency of 43 percent for a full pallet. The reason for the reduction in equivalency over that of a single can is that only one can in the cluster is primed, and the detonation of that single primed can is not sufficient to detonate the whole stack. In all multiple-charge tests, a lot of unburnt propellant was found in the area.

N-5 PROPELLANT SLURRY AND PASTE TEST RESULTS

The airblast parameters were determined for N-5 propellant in its in-process forms. Essentially, these consisted of N-5 slurry, containing 88 percent process water, and two pastes, one containing 30 percent moisture and the other paste consisted of 10 percent moisture. Charge weights ranged from 12 lbs. to 500 lbs. The material was tested in both the settled-out and mixed (or agitated) states and in confined and unconfined configurations. Several charge geometries were evaluated, the material in pipes and the material in tanks or drums.

The basic data obtained from these tests in terms of peak pressure and scaled impulse, and the interpretation of this data in terms of TNT equivalency, is reported on in detail in Reference 2. The maximum TNT equivalency values achieved are shown in Figure 15. Essentially, no blast output was obtained for the slurry and the 30-percent moisture paste. However, the TNT equivalency for the N-5 propellant paste containing 10 percent moisture is 90 percent for pressure and 70 percent for impulse.

CONCLUSION

Figure 15 is a summary of the test results on three materials described in this paper, in terms of maximum values of TNT equivalency. Experiments are currently being carried out on nitroguanidine and its in-process forms. The evaluation of M8 propellant will be started shortly. Reports on the results of tests on nitroguanidine and M8 should be published in February 1973. Plans are also underway to evaluate the blast output of three pyrotechnic compositions in their in-process forms.

The application of the data obtained in these experimental investigations are providing realistic criteria for building construction and quantity-distance siting of new manufacturing facilities. Because of this data, when equivalencies are less than 100 percent, considerable cost savings can be realized in construction of walls and barricades and in land required for safe siting of buildings.

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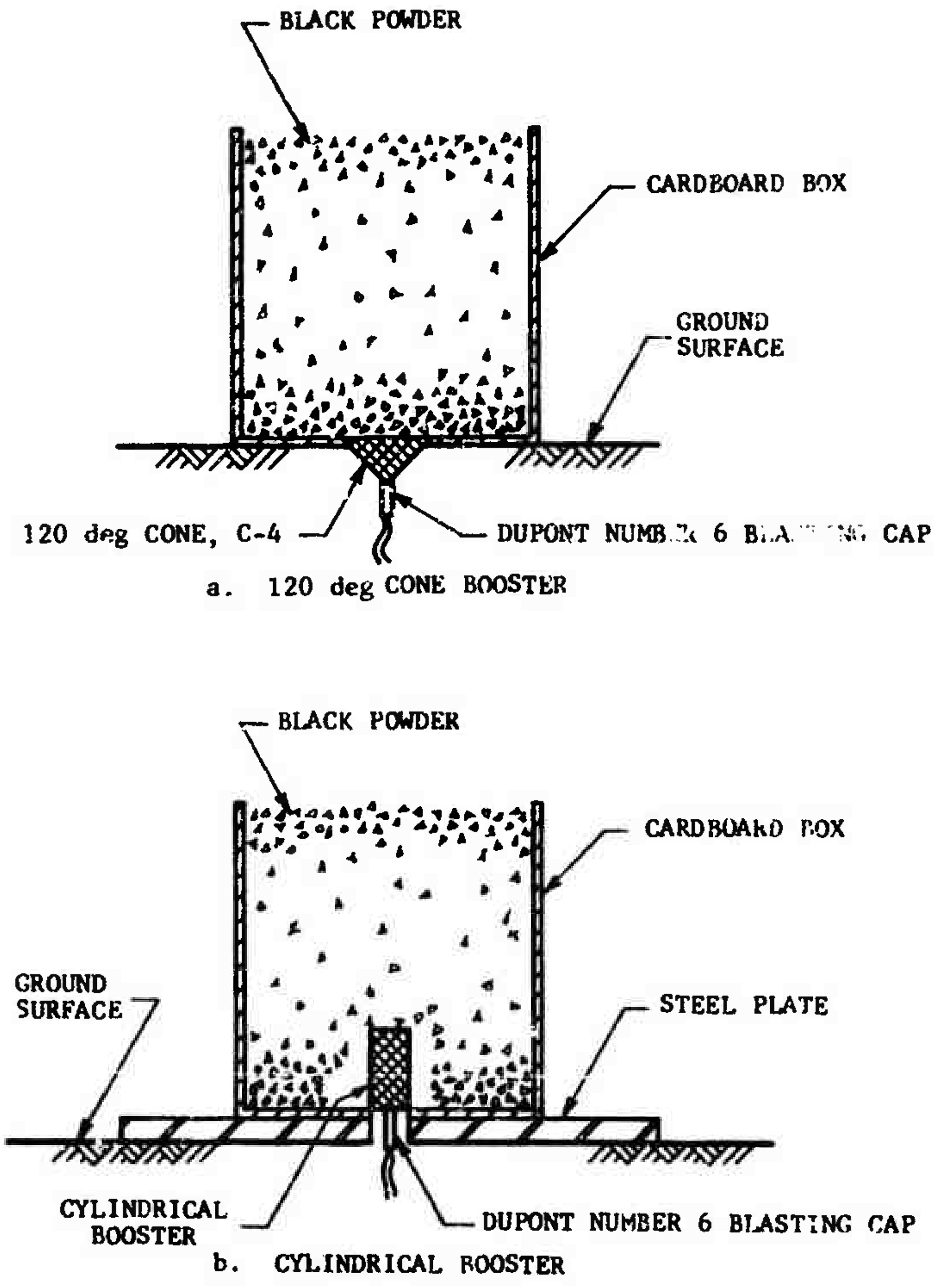


Figure 1. BOOSTER SIZE AND SHAPE TEST SETUP

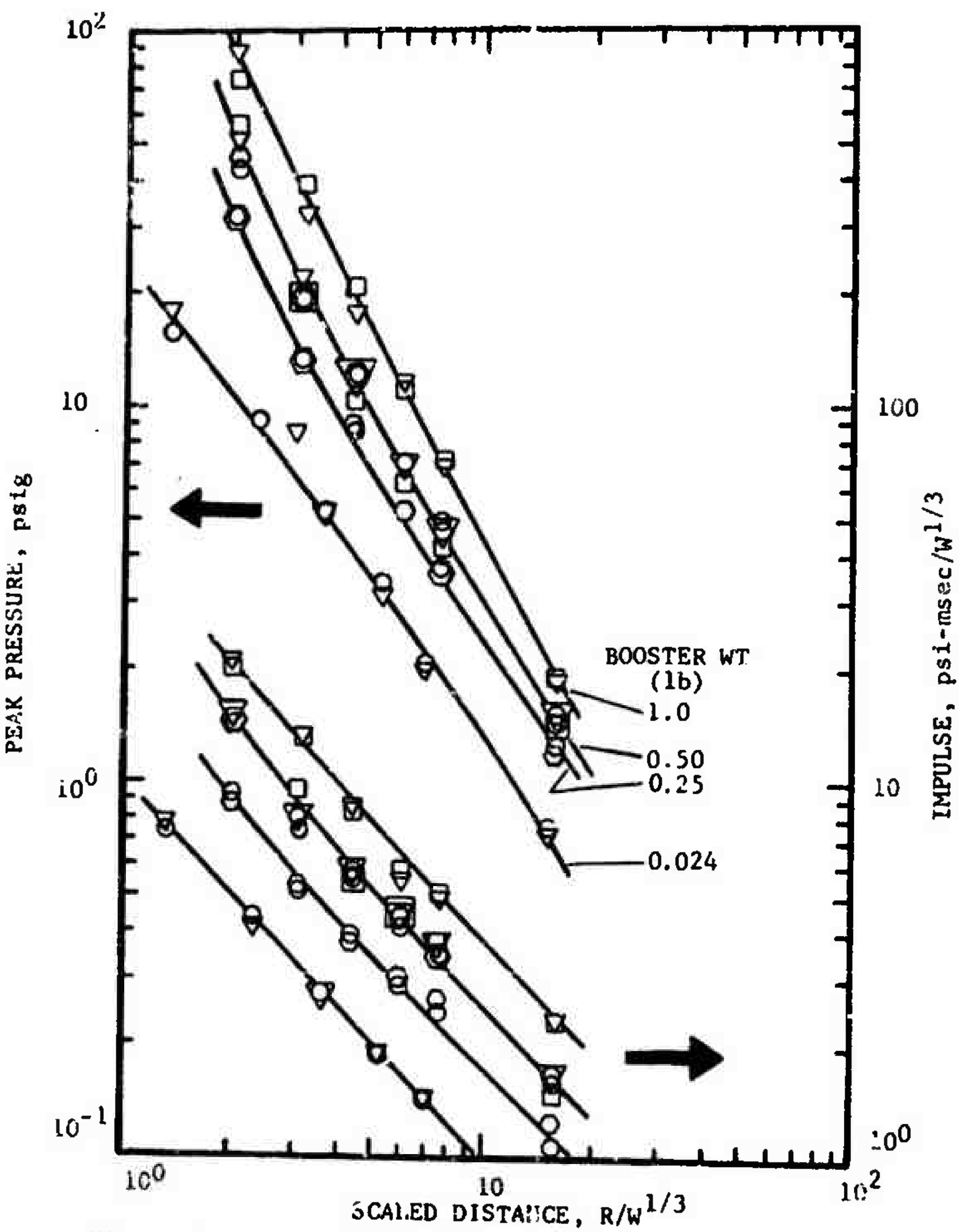


Figure 2. PRESSURE AND SCALED IMPULSE FOR VARIOUS BOOSTER WEIGHTS, 25 LB BLACK POWDER

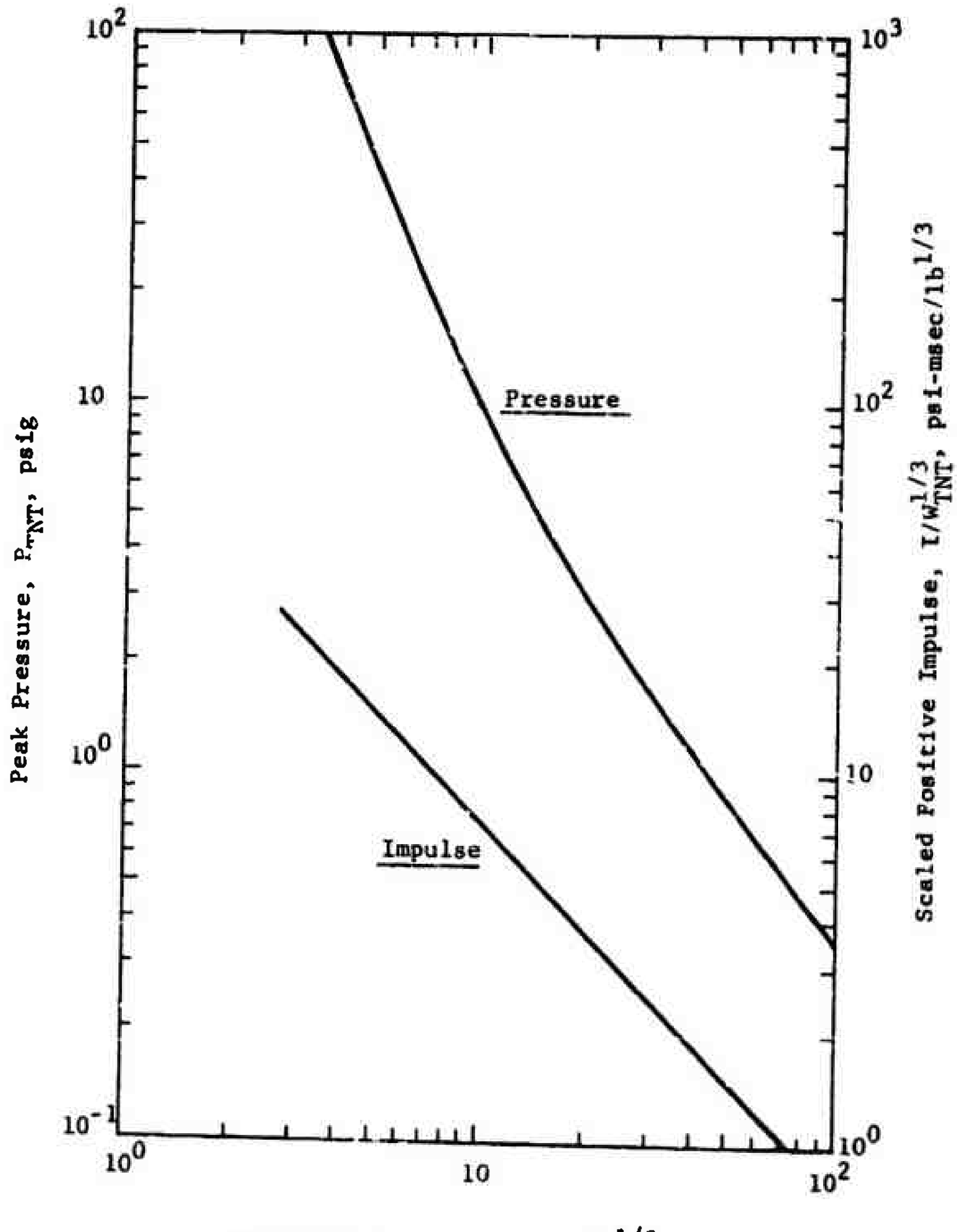


Figure 3. TNT PRESSURE AND IMPULSE REFERENCE CURVE, HEMISPHERICAL SURFACE BURST

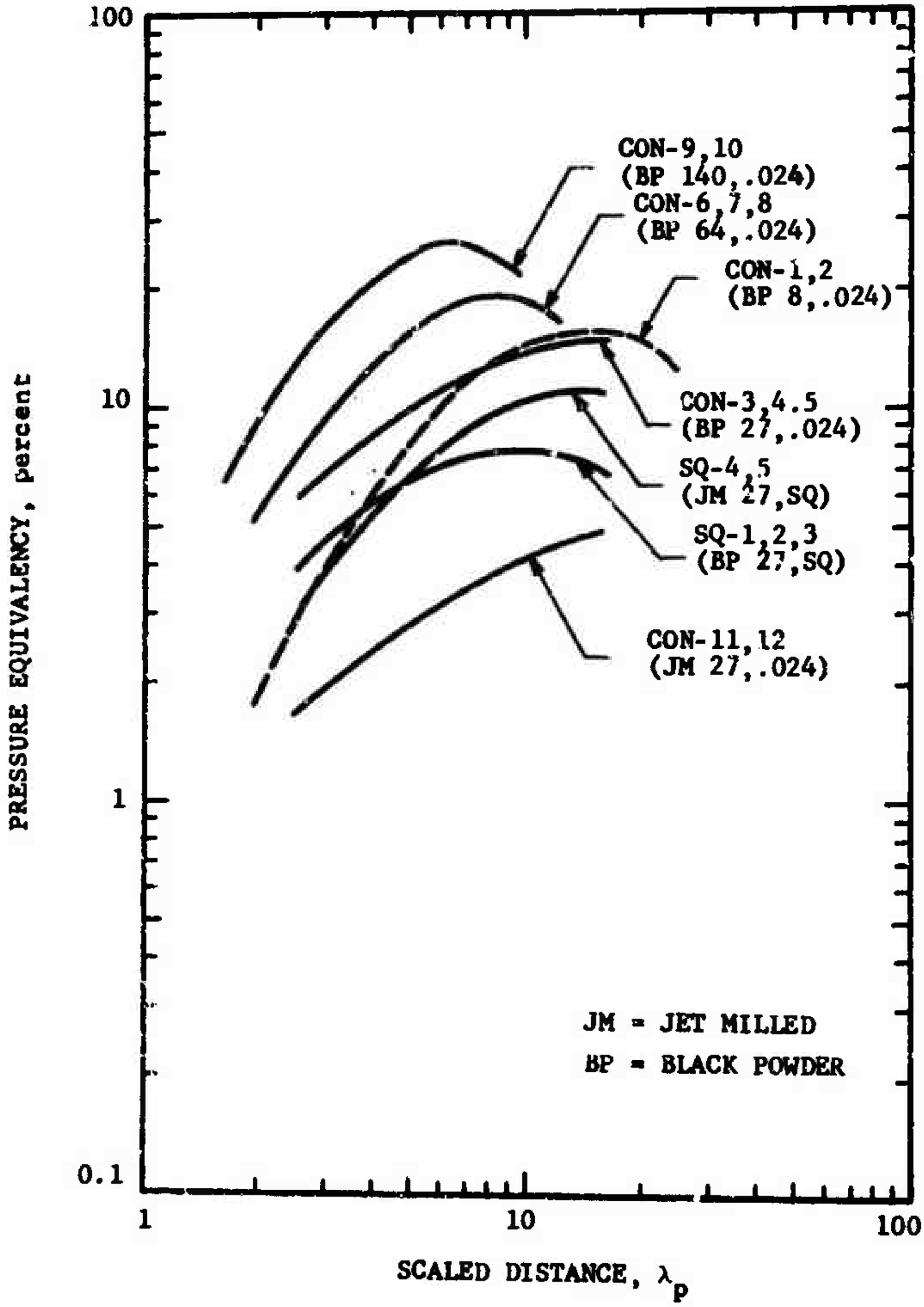


Figure 4. EFFECT OF CHARGE WT ON TNT PRESSURE EQUIVALENCY; CONFINED TESTS, SQUIB OR .024 LB BOOSTER INITIATION

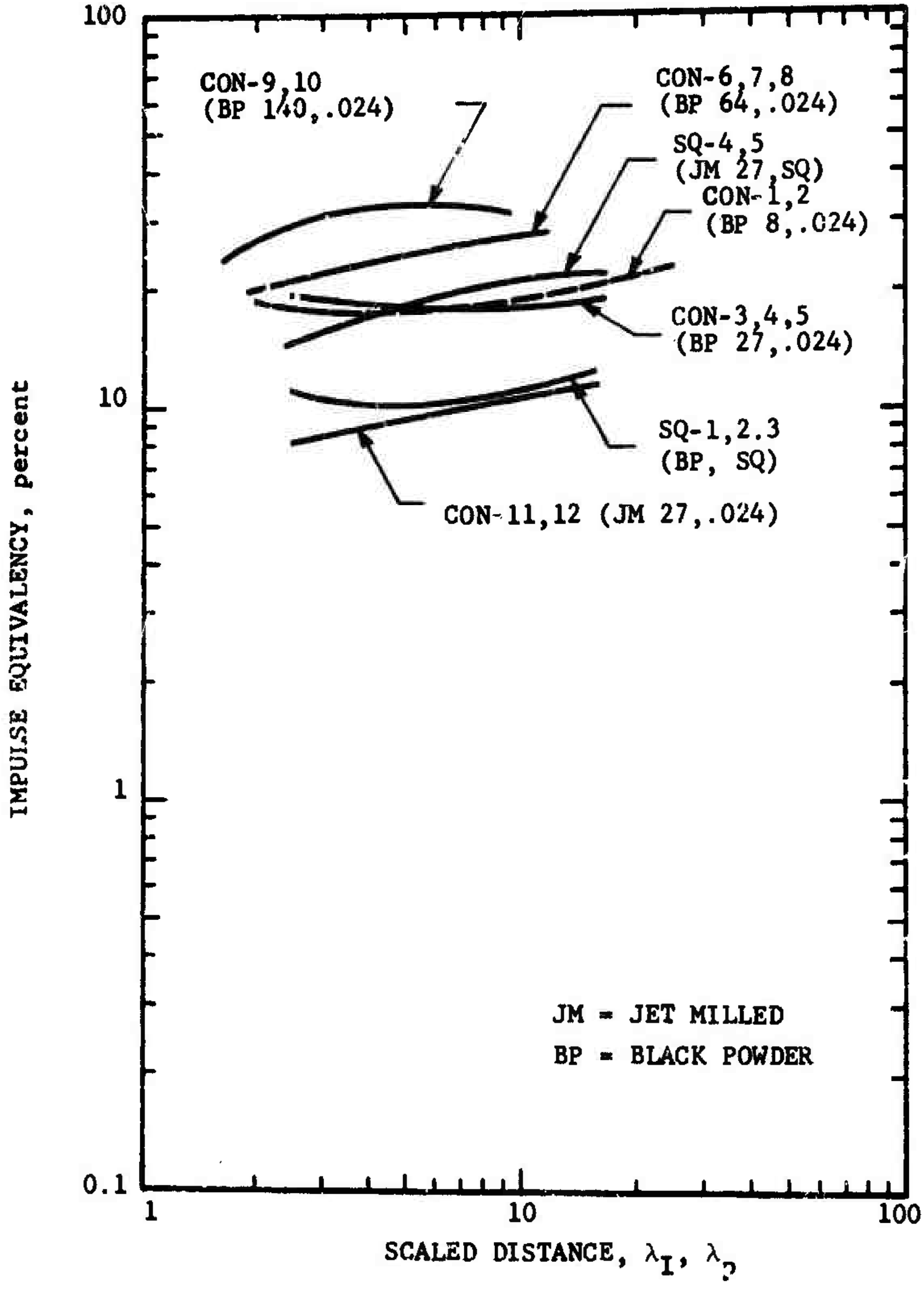


Figure 5. EFFECT OF CHARGE WT ON TNT IMPULSE EQUIVALENCY; CONFINED TESTS, SQUIB OR .024 LB BOOSTER INITIATION

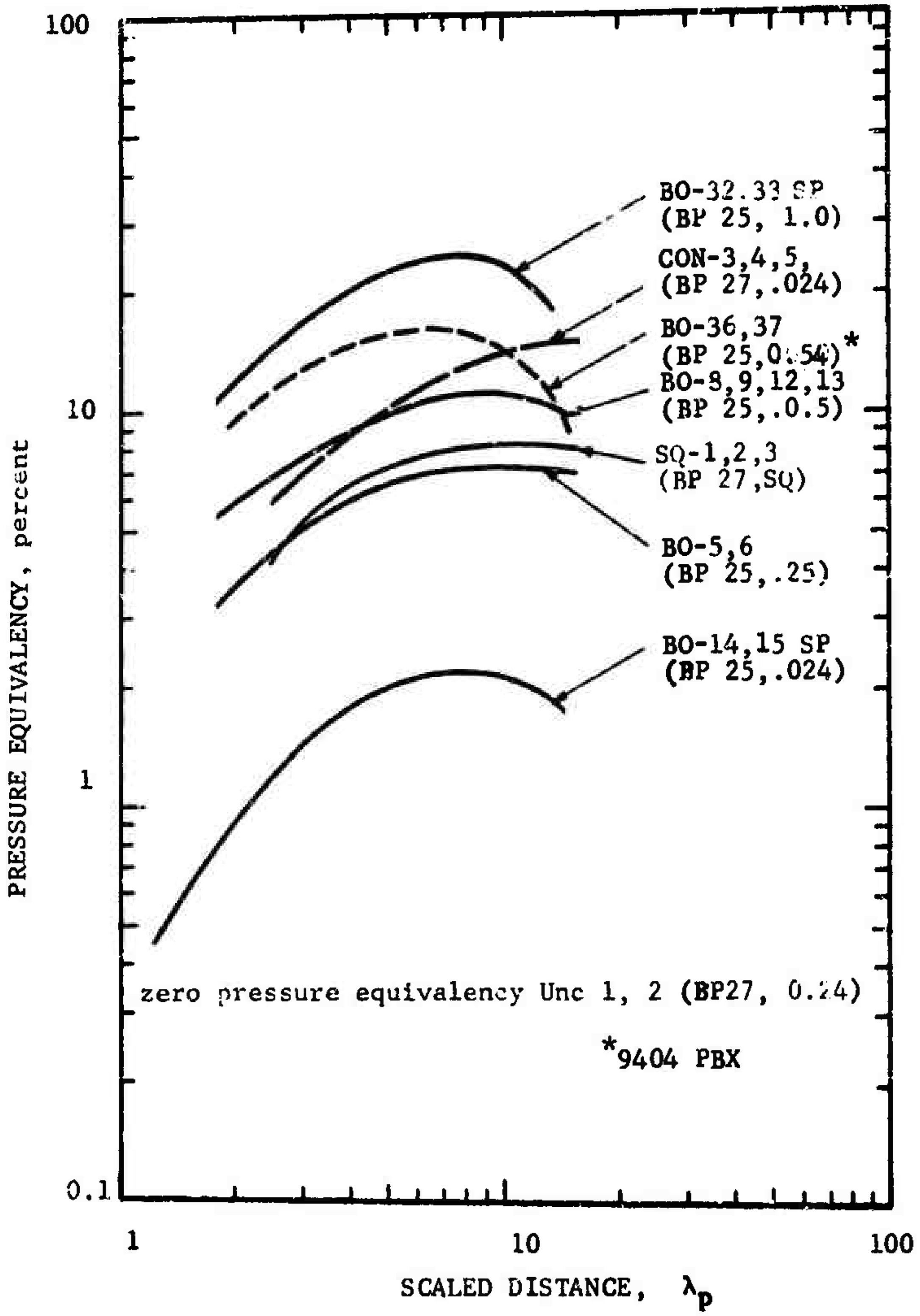


Figure 6. EFFECT OF CONFINEMENT AND BOOSTER WEIGHT ON TNT PRESSURE EQUIVALENCY, 25-27 LB BLACK POWDER

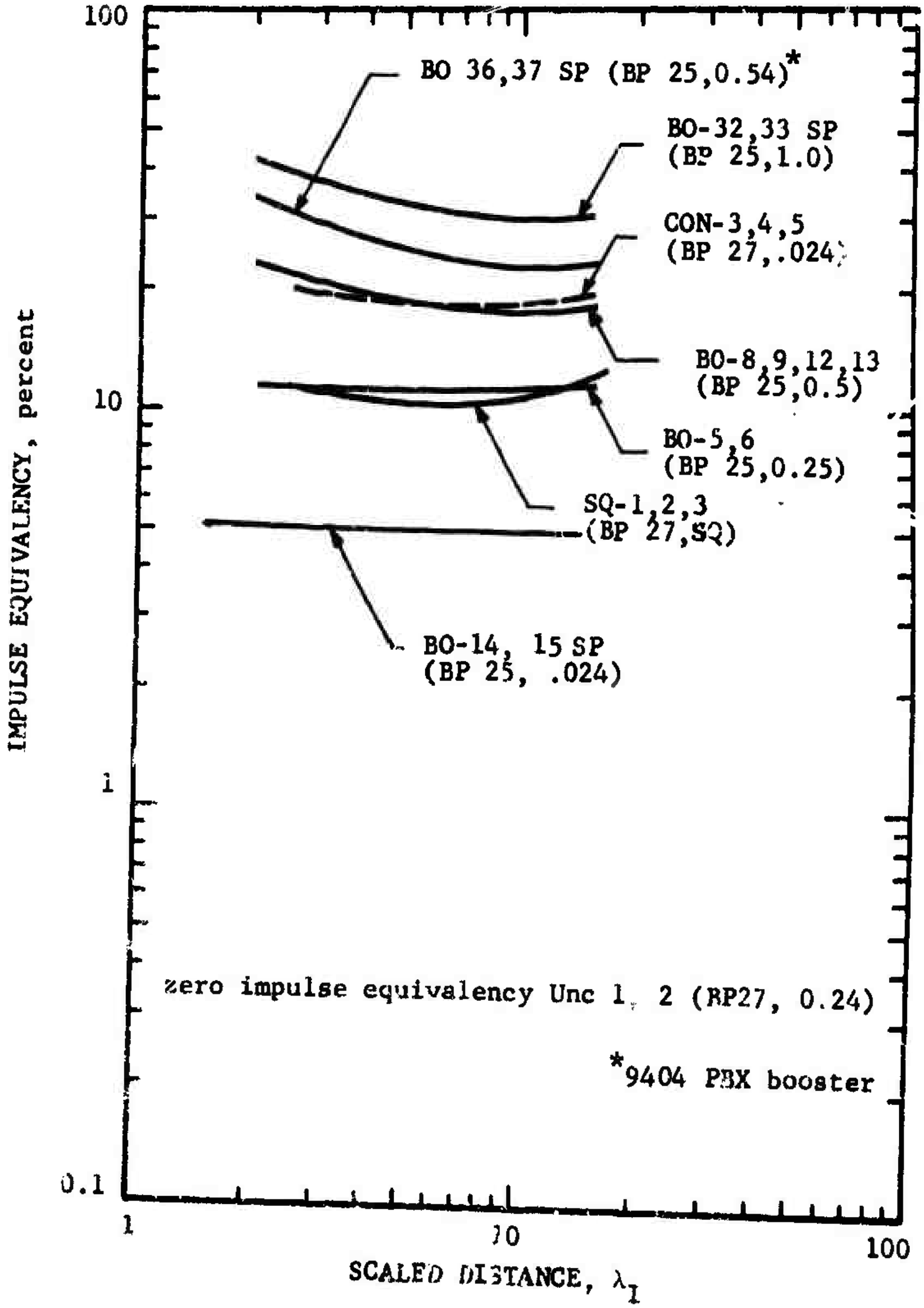


Figure 7. EFFECT OF CONFINEMENT AND BOOSTER WEIGHT ON TNT IMPULSE EQUIVALENCY, 25-27 LB BLACK POWDER

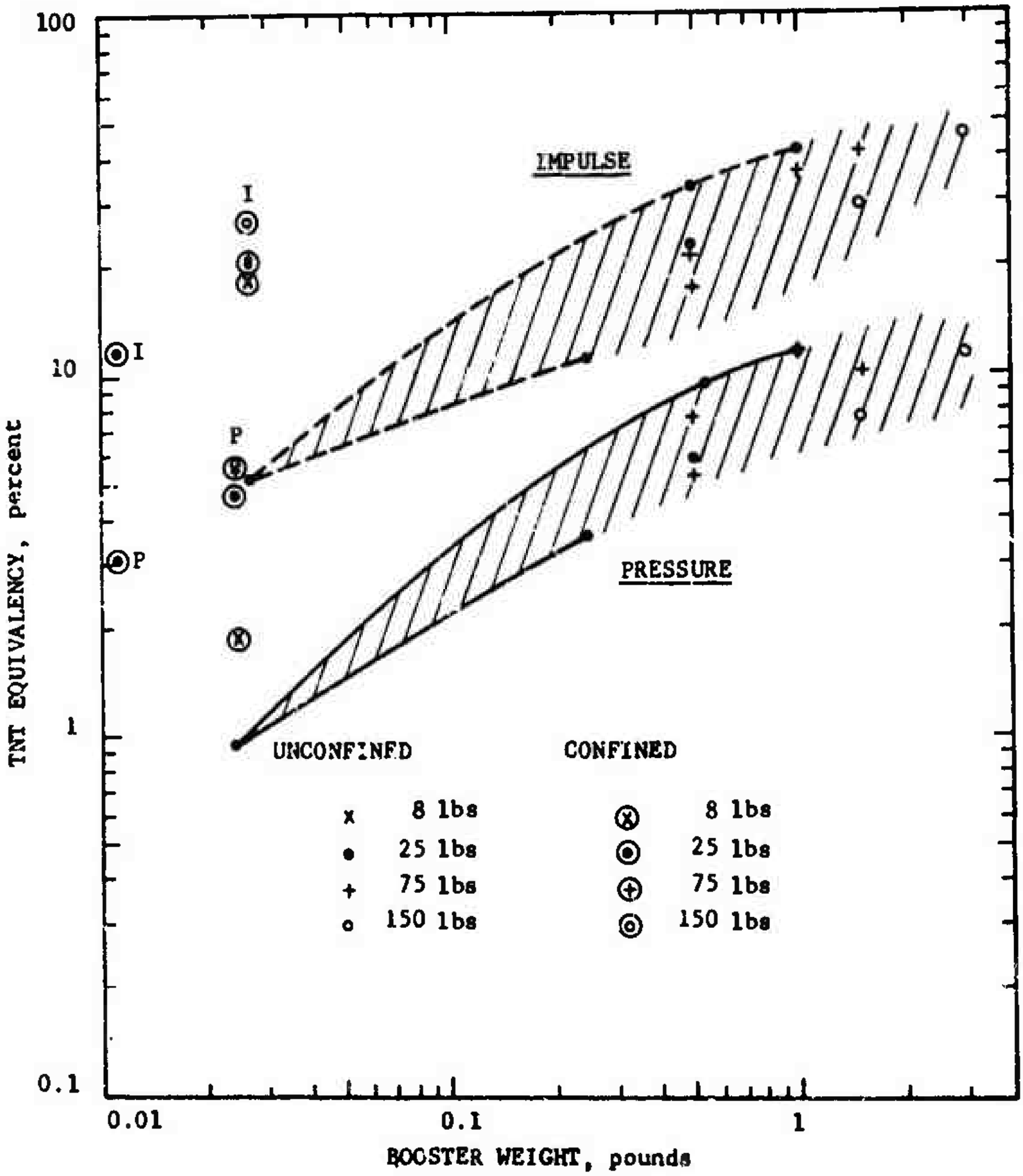


Figure 8. ENVELOPE OF PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF BOOSTER WEIGHT FOR ALL TESTS, SCALED DISTANCE λ=2

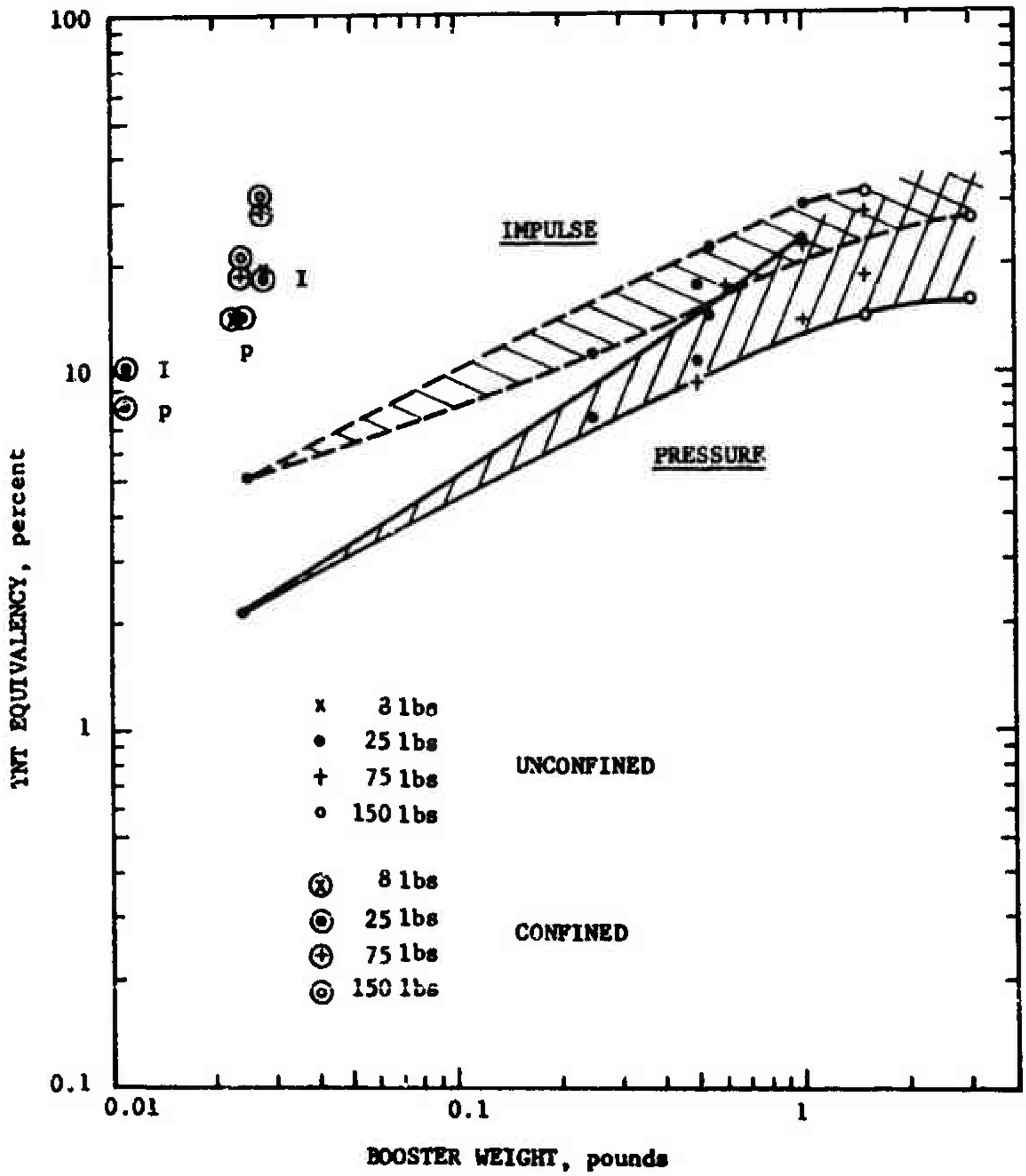


Figure 9. ENVELOPE OF PRESSURE AND IMPULSE EQUIVALENCY AS A FUNCTION OF BOOSTER WEIGHT FOR ALL TESTS, SCALED DISTANCE λ=10

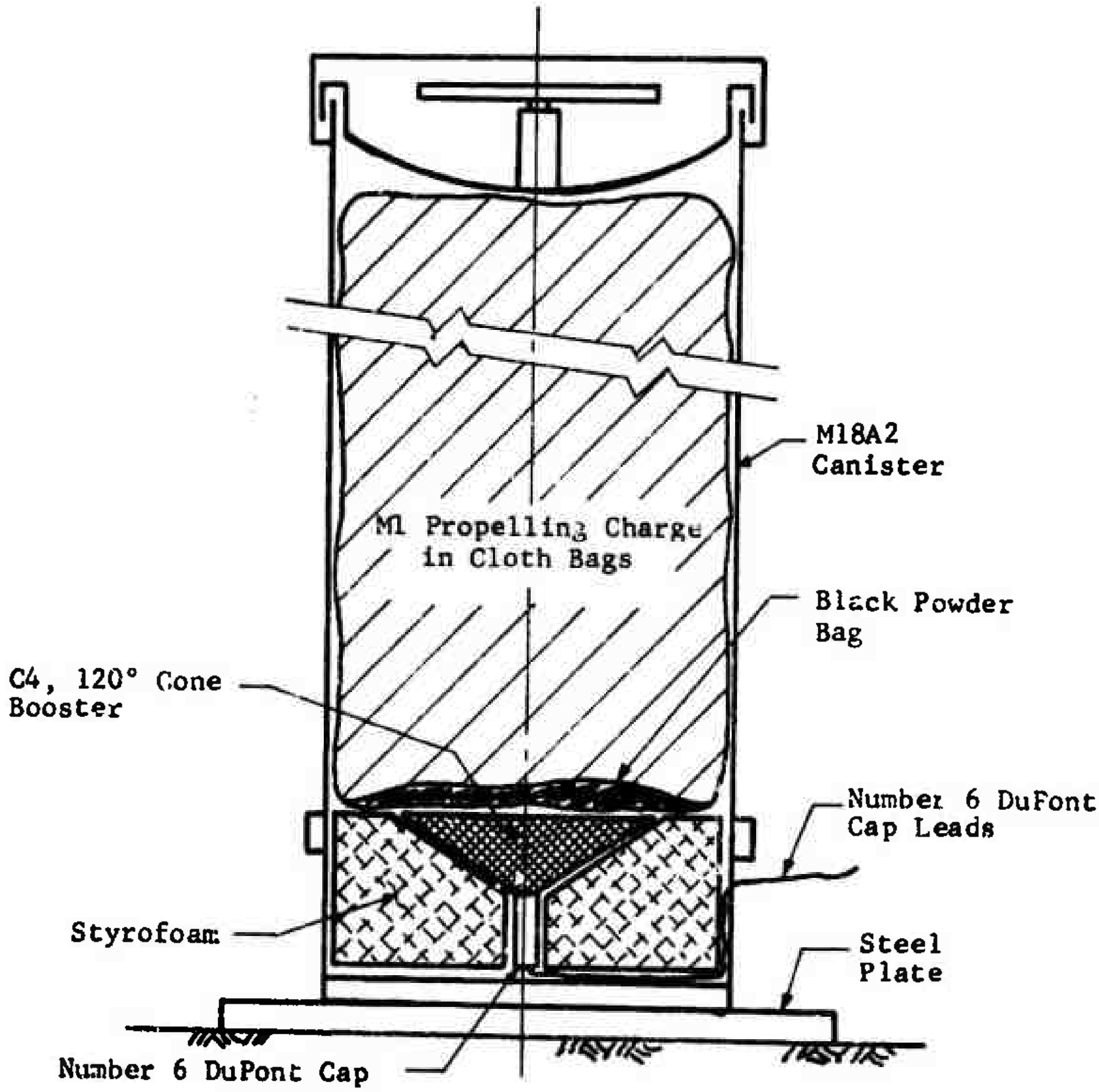
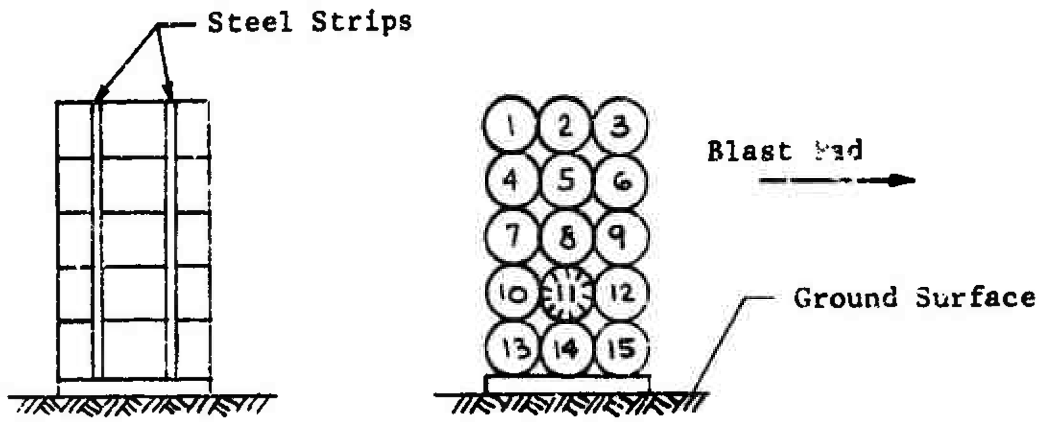
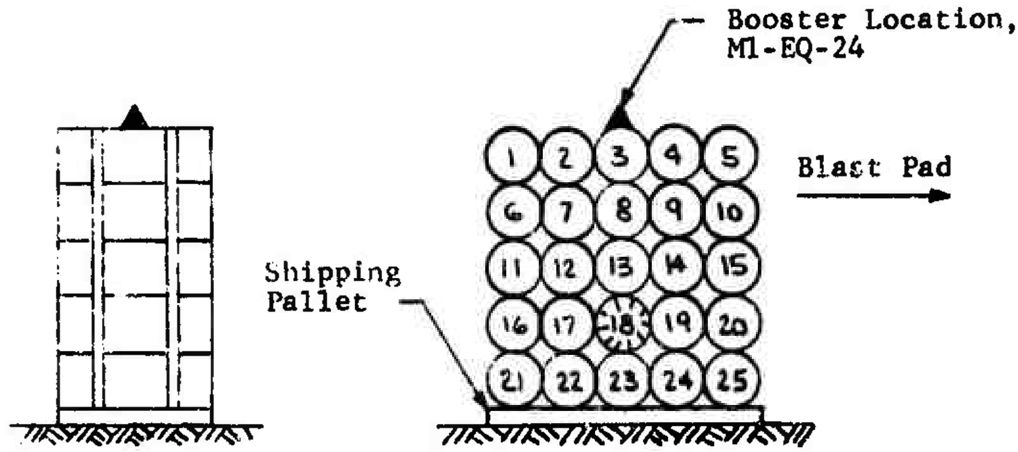


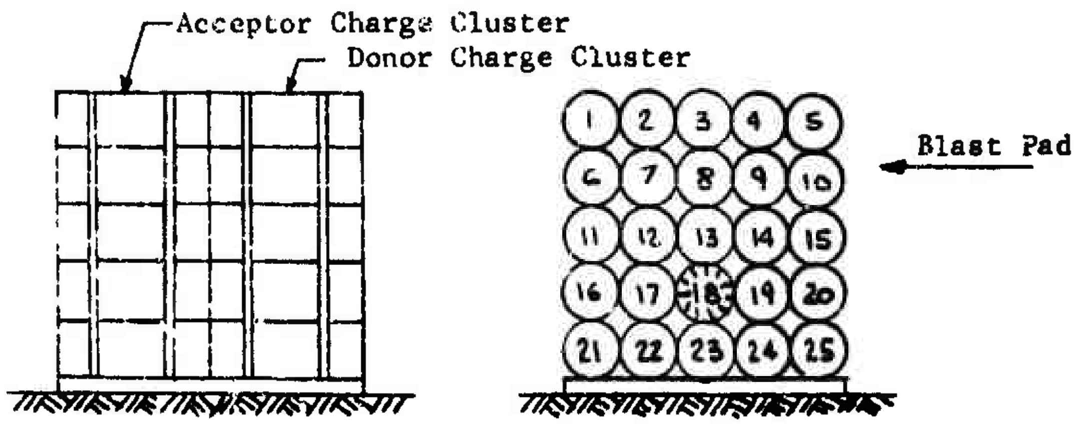
Figure 10. M1 PROPELLING CHARGE SHOWING CONICAL BOOSTER CONFIGURATION USED FOR TNT EQUIVALENCY TESTS



a. Tests M1-EQ-18,19,20



b. Tests M1-EQ-21,24



c. Tests M1-EQ-22,23

Figure 11. MULTIPLE M1 PROPELLING CHARGE TEST CONFIGURATIONS

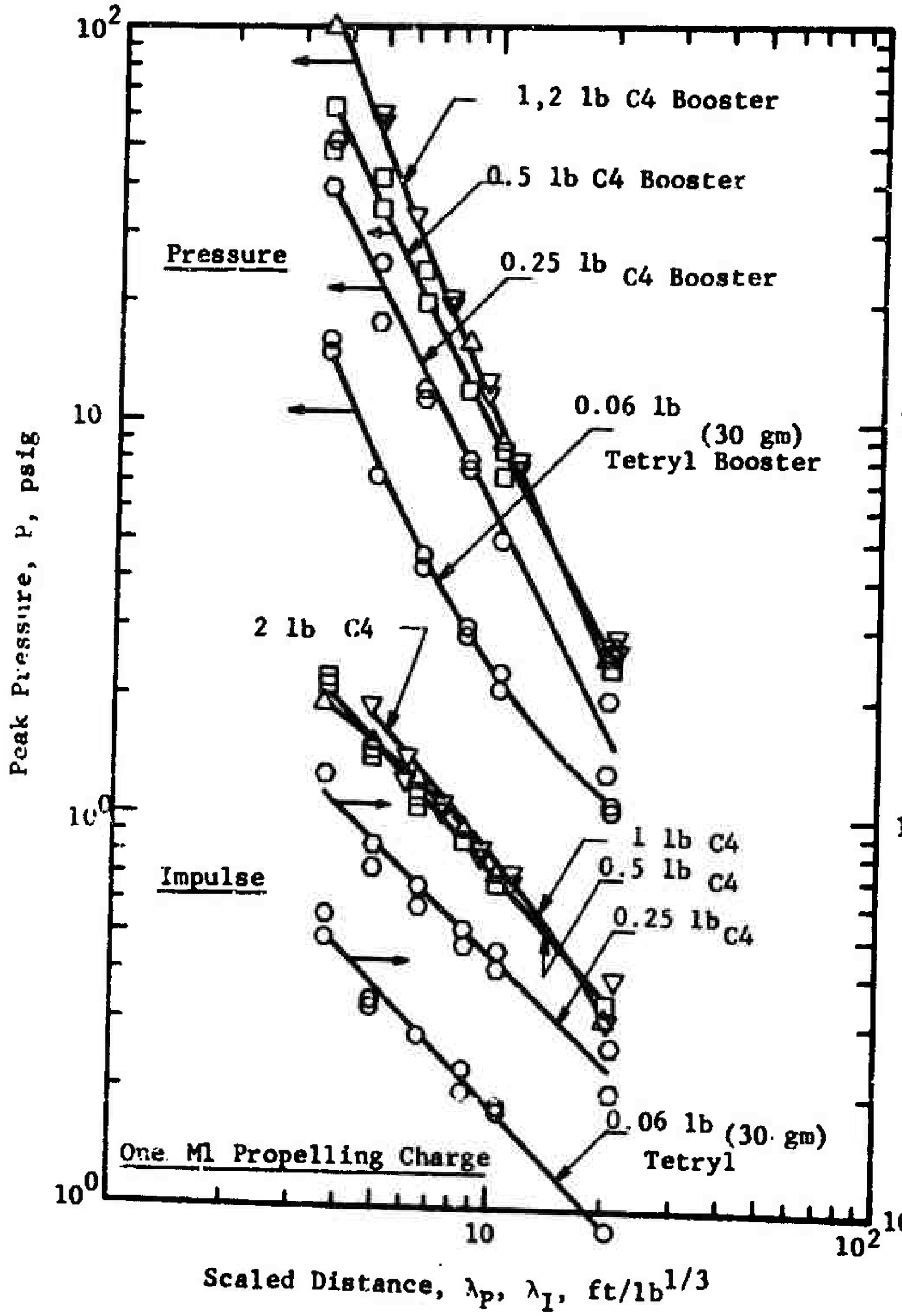


Figure 12. PRESSURE AND IMPULSE, BOOSTER SIZE EFFECTS, ONE M1 PROPELLING CHARGE

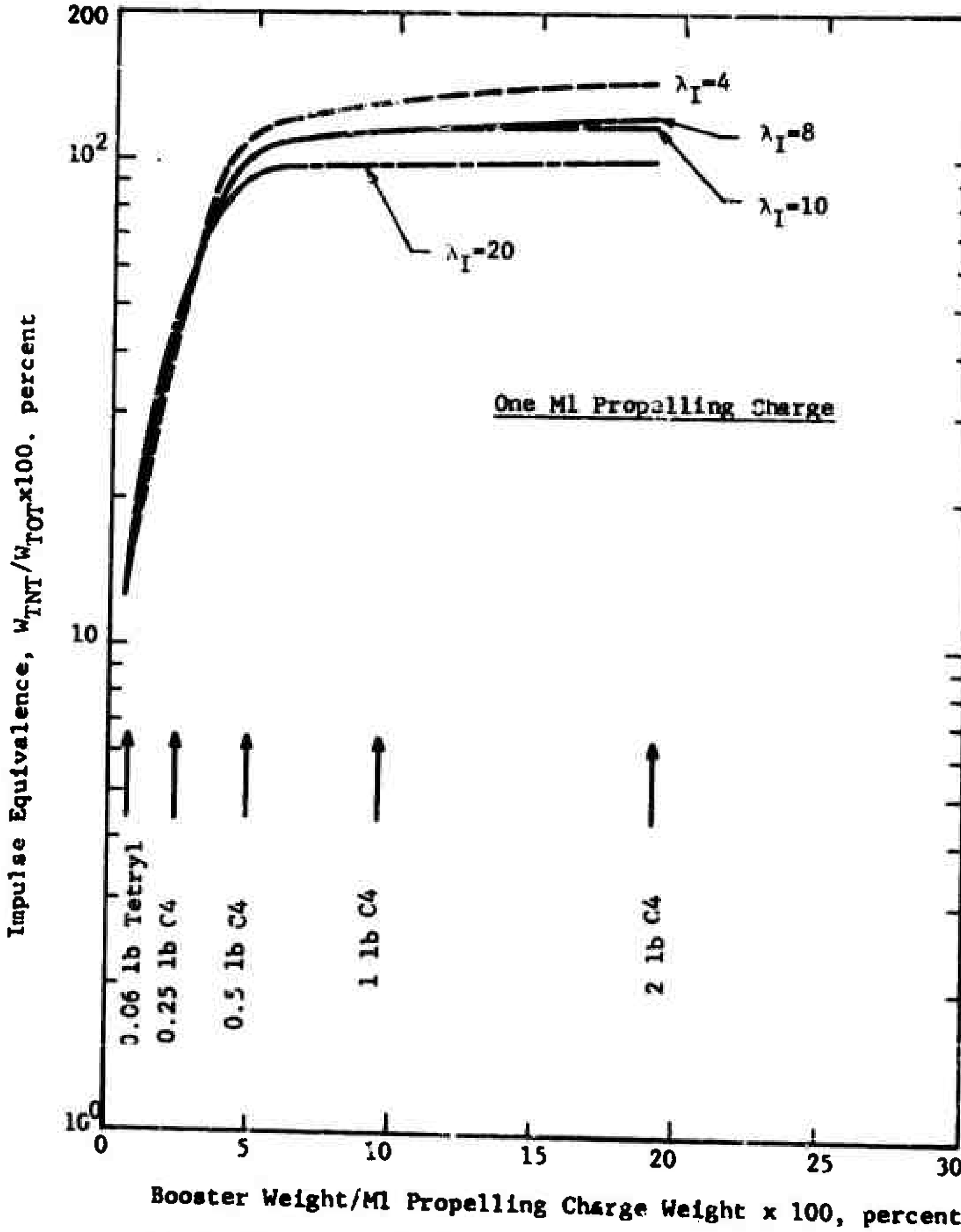


Figure 13. IMPULSE EQUIVALENCY VERSUS BOOSTER SIZE, ONE M1 PROPELLING CHARGE

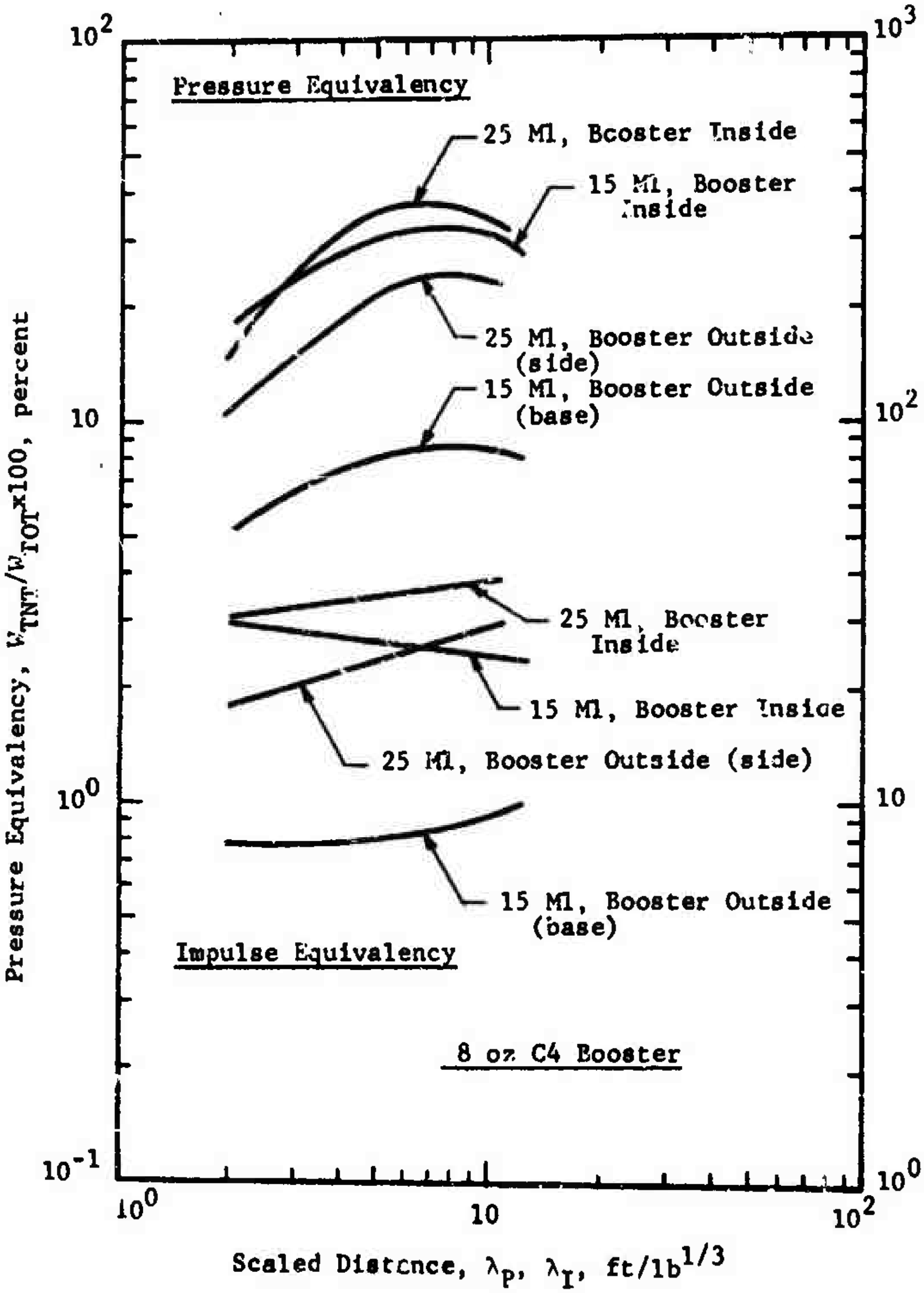


Figure 14. EQUIVALENCIES, BOOSTER LOCATED INSIDE/OUTSIDE CANISTERS, MULTIPLE M1 PROPELLING CHARGES

Figure 15 Summary of TNT Equivalency Test Results

MATERIAL	PRESSURE EQUIVALENCY MAXIMUM (PER CENT)	IMPULSE EQUIVALENCY MAXIMUM (PER CENT)
BLACK POWDER	24	43
M1 PROPELLING CHARGE IN METAL SHIPPING CONTAINER		
SINGLE CANISTER	>100	>100
5 CANISTERS	50	50
15 CANISTERS	30	30
25 CANISTERS	33	40
34 CANISTERS	43	43
N-5 PROPELLANT SLURRY AND PASTE		
SLURRY (88% WATER)	ZERO	ZERO
PASTE (30% WATER)	4	2
PASTE (10% WATER)	90	70
NITROGUANIDINE GUANIDINE NITRATE GUANIDINE NITRATE REACTOR	WORK IN PROGRESS	
M-8 PROPELLANT	WORK TO BE STARTED	
PYROTECHNICS	TEST PLAN PREPARED	

A SAFER BLAST FOR THE MODERN ARMY

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Explosive Excavation Research Laboratory
Livermore, California

Until recently, it was a general consensus throughout many military circles that the Atomic Demolition Munitions (ADM) offered the best and most practical means for implementing the Army's large-scale barrier and denial plans, destroying large targets, and realizing large-scale excavation requirements in the theater of operations. One of the primary reasons for this opinion centers around the outstanding ability of the ADM to crater. However, the nuclear testing limitations imposed by our recent test ban agreements coupled with the tremendous achievements by the explosives industry in the development of ammonium-nitrate-based slurry explosives have resulted in a concerted program to evaluate the utility of commercial slurry explosives in military engineering applications.

The U. S. Army Corps of Engineers is developing chemical explosive excavation as a construction technique for use on Civil Works projects and as a tool for military applications.

The research and development work is being conducted under the auspices of the U. S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory (EERL) located at Livermore, California. This organization was formed in 1962 as the Nuclear Cratering Group (NCG) to carry out the Corps of Engineers (OCE) portion of a joint agreement with the Atomic Energy Commission (AEC) to develop nuclear explosives for construction purposes. The AEC, through the Plowshare Division of the Lawrence Livermore Laboratory at Livermore, California, has been responsible for developing nuclear safety information and methods for predicting the shape of craters. The Army part of the program includes corollary chemical explosive cratering experiments, participation in the AEC's nuclear cratering experiments, and development of project designs and engineering and construction data as a basis for nuclear cratering. It was while NCG was engaged in this research that the advantages of chemical explosive excavation as a useful construction tool became obvious. Since 1969, EERL has promoted the development of both chemical and nuclear explosive excavation design techniques and engineering procedures which can be used for both Military and Civil Works applications.

The experience gained from employing large chemical charges in multiple charge arrays in a variety of media and topographic situations to satisfy actual project construction requirements will be presented in brief during these proceedings by MAJ Richard H. Gates in his paper, "Explosive Excavation - Military Applications." As a result of this experience, EERL has been investigating the feasibility of employing commercial slurry explosives for military engineering applications. The information gained from both civil and military research is integrated into the overall development of explosive excavation. EERL's ultimate goals are the development of chemical explosive excavation as an accepted cost competitive technique

and the development of design criteria and employment concepts for the successful implementation of commercial explosives for both military engineering combat purposes and military construction.

EXCAVATION IN THE "THEATER OF OPERATIONS"

The criteria for employing slurry explosives, the cratering phenomena, and many of the explosive excavation designs and excavation concepts presented in MAJ Gates' paper are applicable for the conceptual military application presented. Slurry explosives in the theater of operations would offer the Tactical Commander a valuable non-nuclear engineer tool for construction, creating barriers and conducting denial operations, and destroying targets. It is conceivable that in the Forward Area of the battlefield, slurry explosives would be invaluable for destroying bridges, creating tank traps, road craters, bunker emplacements, craters in airfields, and implementing access denial operations by ejecta landslides. In the Support Area, which is immediately behind the Forward Area, it is conceivable that slurry explosives on a large scale could be used to create sewage lagoons, reservoirs, or ejecta dams as well. Because of the relative success commercial explosives manufacturers have experienced in changing the operations of our commercial quarries with ammonium-nitrate-based explosives, slurries could be employed to create rock quarries throughout the theater of operations depending upon the requirements for aggregate and the topography situation.

Before reviewing some of the experimental work planned and completed and discussing the proposed long-range plan for making our demolition work safer and easier, it is essential to obtain an appreciation for some of the principal types of U. S. explosives commonly used for military purposes, as well as the basic composition and variety of commercial slurries available on the market today. Table 1 presents the characteristics and uses of the principal U. S. explosives.

As Table 1 readily demonstrates, the military has a large family of explosives capable of performing satisfactorily over a wide range of operational requirements. Generally TNT and Composition C4 are considered the Army's primary general purpose explosives. Along with Composition C3, Composition B, Sheet Explosive, PETN, Tetryl, and Anatol, they perform generally where a powerful explosive is needed for hard target destruction and as components for blasting caps, boosters, and other explosive devices. The 40-lb ammonium nitrate canister is the Army's sole non-nuclear cratering charge, while commercial and military dynamites form the heart of the construction explosives. While theoretically each explosive could perform any one of the above tasks, their characteristics make them best suited for the tasks indicated in Table 1. In fact, while dynamites can be used on the battlefield, it is only under special conditions that they are employed in forward areas.

Slurries or water gels are ammonium nitrate-based explosives which have been developed commercially to provide a variety of dense, easily handled, water-resistant products for commercial blasting operations. Though the term slurry is commonly used to encompass all such products, slurries are classified as slurry explosives when they are cap sensitive or

Table 1. Characteristics of Principal U.S. Explosives
(Taken from FM 5-25)[1]

Name	Principal military use	Relative effectiveness as external charge	Velocity of detonation, fps	Value as cratering charge	Intensity of poisonous fumes	Water resistance	Packaging
TNT	Main charge, booster charge; cutting and breaching charge, general and military use in forward areas	1.00	23,000	Good	Dangerous	Excellent	1 lb, 50 or 56 to box
Tetrytol, M1, M2		1.20	23,000	Fair	Dangerous	Excellent	16 2-1/2-lb blocks in wooden box
Composition C3 M3, M5		1.34	25,000	Excellent	Dangerous	Good	16 2-1/4-lb blocks in wooden box
M5A1 Composition C4 M112		1.34	26,000	Excellent	Slight	Excellent	24 2-1/2-lb blocks in wooden box
Ammonium nitrite (cratering charge)	Cratering and ditching	0.42	14,800	Excellent	Dangerous	Poor	40-lb charge in metal can
Sheet explosive M186, M118 charge demolition	(See C-4)	1.14	24,000	Poor	Slight	Excellent	80 1/2-lb sheets/box 25-lb roll
Military dynamite M1	Quarrying stumping-ditching	0.92	20,000	Good	Dangerous	Good	1/2-lb 100 to box

Table 1. Characteristics of Principal U.S. Explosives - Continued

Name	Principal use	Relative effec-tiveness as external charge	Velocity of detona-tion, fps	Value as cratering charge	Intensity of poison-ous fumes	Water resist-ance	Packaging
Straight dynamite (Commercial) 40% 50% 60%	Land clearing, cratering, quarrying, and general use in rear areas, such as ditching and stumping	0.65 0.79 0.83	15,000 18,000 19,000	Good	Dangerous	Poor Good Excel-lent	102 Sticks 103 per 106 50 lb box
Ammonia dynamite (Commercial) 40% 50% 60%		0.41 0.46 0.53	8,900 11,000 12,700	Excellent	Dangerous	Good Good Good	110 Sticks 110 per 50 110 lb box
Gelatin dynamite 40% 50% 60%		0.42 0.47 0.76	8,000 9,000 16,000	Good Good Good	Slight	Good {Very {Good	Sticks per 50 lb box
PETN	Detonating cord Blasting cap	1.66	20,000 24,000	NA	Slight	Good	
Tetryl	Booster charge	1.25	23,400	NA	Dangerous	Excel-lent	
Composition B	Bangalore torpedo	1.35	25,000	Good	Dangerous	Excel-lent	Bulk
Amatol 80/20	-do-	1.17	16,000	Excellent	Dangerous	Poor	

Table 1. Characteristics of Principal U.S. Explosives - Continued

Name	Principal use	Relative effectiveness as external charge	Velocity of detonation, fps	Value as cratering charge	Intensity of poisonous fumes	Water resistance	Packaging
Black Powder	Time blasting fuse	0.55	1310 Max. Depends on Confinement	Fair	Dangerous	Poor	Bulk
Nitrostarch	Substitute for TNT	0.80	15,000	Good	Dangerous	Satisfactory	1-lb blocks

contain high-explosive ingredients and categorized as slurry blasting agents when they do not contain such ingredients. Slurry explosives are usually sensitized with cap sensitive products such as TNT or nitro-starch, while fuels such as sulfur, carbon, or aluminum are found in slurry blasting agents. Presently the majority of slurries available on the commercial market are not cap sensitive and thus they are often grouped under the term blasting agent. Using the definition of blasting agent established by the National Fire Protection Association (NFPA, 1972), this is not correct. Therefore, before a particular slurry can be shipped or employed, its classification must be checked to insure all pertinent safety rules and regulations are being observed.

Organic gums such as guar gum are used to thicken and gell slurries giving them considerable water resistance. These gelling agents insure a homogeneous mixture, prevents setting of the slurry components, and facilitate handling. The gelling agent can be mixed while the explosive is being pumped into the emplacement cavity allowing the slurry to cure to a rubbery or jelly-like solid which is water resistant. For small-scale operations, manufacturers mix the slurry to its final consistency and prepackage it. Excellent coupling with the surrounding medium is thus assured and void spaces within the explosive are minimized. The consistency of most slurries ranges from fluid near 38° C (100°F) to rigid at freezing temperatures, although some slurries maintain fluidity even at freezing temperatures.

Typical slurries contain from 40 to 75% ammonium nitrate, 10 to 25% water, 1 to 5% stabilizing and gelling agents, and the remainder consists of aluminum, high explosive, or both. The addition of large quantities of aluminum to slurry blasting agents produces an explosive with a very high energy release at moderate detonation pressures. Properties of some typical slurries are given in Table 2.

Ammonium nitrate slurries are frequently shipped and stored in plastic bags. They can be stored in most containers, including aluminum or steel (unless HNO_3 is a constituent); however, because the slurries are new, effects of long-term storage are not well known. Due to the large amount of water contained in slurry blasting agents, they are very insensitive to flame and are extremely difficult to burn. They are neither cap sensitive nor more importantly can they be detonated by bullet impact. Their compressibility is low and thus they can be used under hydrostatic loads. They contain no headache-producing ingredients and have unconfined critical diameters of three inches. Handling, loading, and storage problems connected with slurries appear much easier than those associated with dynamites, TNT, or other military high explosives.

To date we have not fully evaluated the potential impact of slurries on many of the demolition requirements in Table 1. We have, however, conducted extensive tests of the cratering effectiveness of blasting agents and slurries as compared to TNT and other basic explosives. As is readily apparent from Table 2, the slurries tested thus far have proven very effective.

Table 2

Measured properties and calculated parameters of representative cratering explosives.

(Taken from NCG TR-21)[3]

Explosive	Detonation pressure (kbar)	Bulk specific gravity	Detonation velocity (m/sec)	Contains HE	Heat of detonation (cal/g)	Nominal cost ($/lb)	Excavated volume relative to equal weight of TNT[a]
ANFO	60	0.93	4560	No	890	0.06±0.04	1.0 - 1.1
AN Slurry	104	1.40	6050	Yes	730	0.15±0.05	1.0 - 1.2
AN Slurry (2% Al)[b]	60	1.30	4300	No	750	0.08±0.05	1.0 - 1.2
AN Slurry (8% Al)[b]	66	1.33	4500	No	1110	0.13±0.05	1.2 - 1.4
AN Slurry (20% Al)[b]	85	1.30	5700	No	1450	0.20±0.07	1.5 - 1.7
AN Slurry (35% Al)[b]	81	1.50	5000	No	1950	0.25±0.10	1.6 - 1.8
TNT	220	1.64	6930	N/A	1102	0.25±0.05	1.00

[a]That is, "Createring Effectiveness" as measured by small-charge detonations in sand. Absolute cratering performance in terms of volume excavated per pound of explosive depends on the size of the shot; it is less for larger shots. Relative performance, on the other hand, is not as sensitive to charge size.

[b]Slurry blasting agent.

RELATED EXPERIMENTAL PROJECTS

Projects TANK TRAP and ARMOR OBSTACLE I conducted in 1964 and 1971, respectively, were vivid examples of the ability of chemical explosives to produce effective obstacles.

Project TANK TRAP[2] was conducted in September 1964 at the Nevada Test Site to determine the ability of selected tactical vehicles to traverse craters typical of those which could be produced with large ADM's. The project consisted of three detonations, two of which were chemical and the other nuclear. Trafficability tests of the vehicles were performed in the SCOOTER Crater, produced by 500 tons of TNT buried at 125 feet, the Pre-SCHOONER BRAVO Crater, produced by 20 tons of nitromethane buried at 51 feet, and the JANGLE U Crater, produced by a 1.2-kt nuclear device buried at 17 feet. Dimensions of the craters produced by these detonations are presented in Table 3.

The results of these experiments indicated that: (1) craters formed in dry soil by the detonation of explosives at the surface or at very shallow depths of burst (JANGLE U) do not present significant trafficability problems to tracked tactical vehicles; (2) craters formed by explosions at or near optimum depth of burst in dry soil (SCOOTER) are formidable obstacles to tracked vehicles, and (3) craters formed in hard rock such as basalt shown in Figures 1 and 2 (Pre-SCHOONER BRAVO) cannot be negotiated by tracked tactical vehicles without major modification of the crater and/or assistance by heavy-duty equipment, either mobile or fixed.

On a smaller scale, Project ARMOR OBSTACLE I was conducted in November 1971 near the Ft. Peck Reservoir, Ft. Peck, Montana, to determine the effectiveness of the three craters produced in conjunction with Project DIAMOND ORE (DO), Phase IIA. Selected tactical vehicles obtained from the Montana National Guard were utilized to determine the navigability and effectiveness of the crater. Trafficability tests were performed in DO craters IIA-1 and IIA-2, each produced by 10 tons of aluminized ammonium nitrate slurry buried at 41 feet and in DO IIA-3 produced by the same size charge buried at 19.7 feet. Apparent crater dimensions for these detonations are also presented in Table 3. The results of the experiments indicated that charges detonated at optimum depth of burst do produce craters with significant trafficability problems to tracked tactical vehicles similar to the M48A1 tank. Crater IIA-1, formed at or near optimum depth of burst, presented less of an obstacle than either IIA-2 or IIA-3 as the tank was able to successfully exit the crater after 15 minutes and several attempts. Crater IIA-2 also detonated at or near optimum depth of burst, presented a more formidable obstacle than IIA-1, as shown in Figure 3. After 20 minutes and several unsuccessful attempts to exit the crater as shown in Figure 4, the tank had to be assisted by a piece of heavy-duty equipment. Although the DOB for crater IIA-3 was only 6 meters, the crater also proved to be an unnegotiable obstacle. After a considerable time and several unsuccessful attempts, the tank was retrieved with the assistance of a heavy-duty dozer. Following this maneuver, the dozer cut a trench through the crater by pushing in the friendly side and back-blading on the enemy side as shown in Figure 5. The efforts of the dozer did significantly reduce the problem of traversing the crater. A total of 41 minutes

TABLE 5

Crater Dimensions for Projects TANK TRAP and ARMOR OBSTACLE I

Project	Crater	Lip to Lip Diameter (ft)	Depth (ft)
TANK TRAP			
	SCOOTER	310	75
	JANGLE U	260	53
	Pre-SCHOONER BRAVO	98	25
ARMOR OBSTACLE I			
	IIA-1	127	24.5
	IIA-2	125.4	22.6
	IIA-3	120.6	31.2

was expended by the dozer preparing the cut, and the tank made 12 attempts in 9 minutes, as shown in Figure 6, before successfully exiting the crater. The individual pictured in Figure 7 is convinced that craters produced by slurry explosive for Project DIAMOND ORE do present formidable obstacles.

Several recent Civil Works projects conducted by the Explosive Excavation Research Laboratory, while not connected with the feasibility of slurry explosives for military operations in the field of construction did demonstrate several applicahle construction techniques. Military engineering does not normally concern itself with the design of relatively permanent structures; instead its purpose is to provide for theater of operations construction for a 2- to 5-year time frame. Throughout recent operations in Southeast Asia, the military engineer has found himself increasingly involved in horizontal as well as vertical construction. This has necessitated much work in the area of quarries and road cuts.

Project LOST CREEK, conducted from April to July of this year near Medford, Oregon, was designed to provide valuable information on several areas of interest, primarily controlled blasting techniques and mounding shots (breaking rock in place using large charges and excavating it by mechanical methods). The project was carried out at a prospective quarry site in basalt, and a series of experimental blasts using two different slurries and ANFO were conducted. These detonations demonstrated the feasibility of obtaining quarry rock using deeply-buried charges while reducing the associated problems of rock throw and blast effects. One such row shot consisted of 1400 pounds of explosive distributed in seven charges; the detonation produced the mound shown in Figure 8. This particular

Fig. 1 - Project TANK TRAP, M-60 Tank Unable to Negotiate in Hard Rock of Pre-SCHOONER Crater.

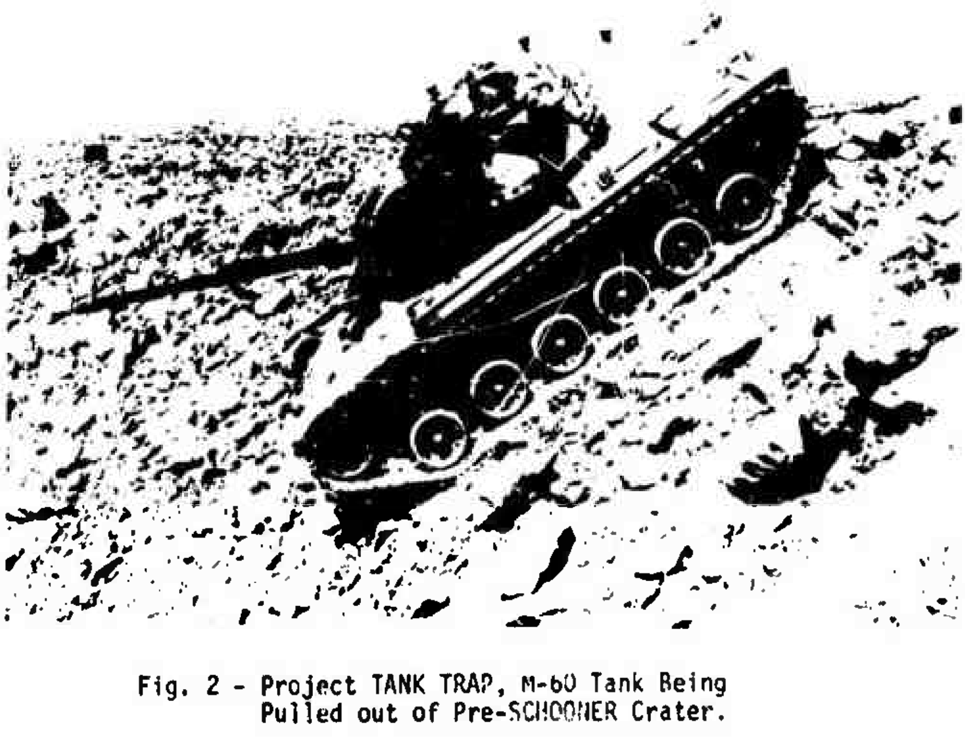

Fig. 2 - Project TANK TRAP, M-60 Tank Being Pulled out of Pre-SCHOONER Crater.

Fig. 3 - Project ARMOR OBSTACLE, M-48 Tank Attempting to Exit D.O. Crater IIA-2

Fig. 4 - Project ARMOR OBSTACLE, M-48 Tank Tracks Indicating an Unsuccessful Attempt to Exit D.O. Crater IIA-2 Unassisted.

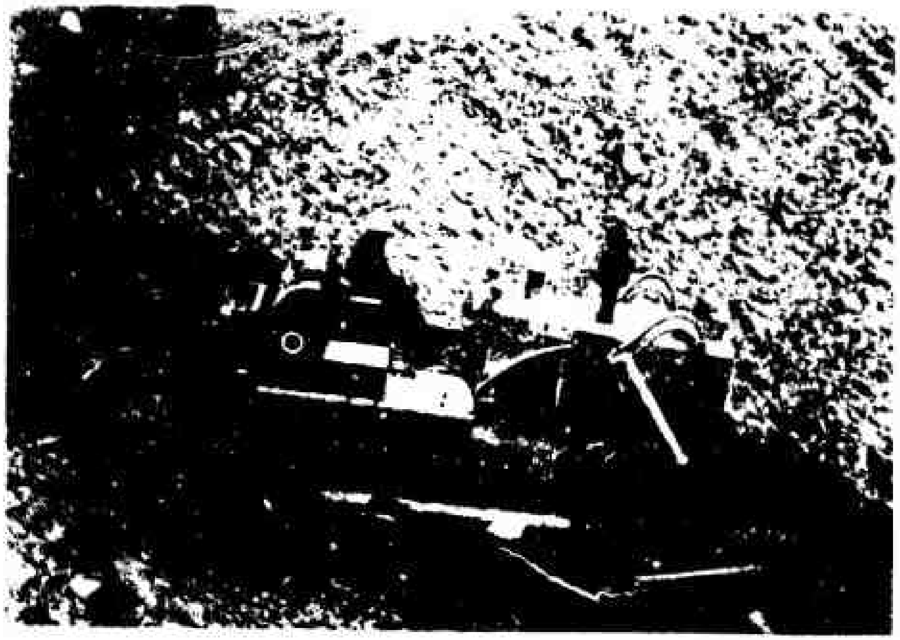

Fig. 5 - Project ARMOR OBSTACLE, Dozer Preparing an Exit Channel in D.O. Crater IIA-3.

Fig. 6 - Project ARMOR OBSTACLE, M-48 Tank Exiting DO Crater IIA-3 after Dozer Work.

Fig. 7 - Yes, It's an Obstacle. Project ARMOR OBSTACLE, Semi-Aerial View of DIAMOND ORE Crater IIA-3.

mound was excavated and produced approximately 1500 cubic yards of material which will be ideally suited for rock-fill or subsequent crushing for aggregate or road material. (See Figure 9.)

Project LIBBY, conducted in May and June of this year near Libby, Montana, consisted of explosively-excavating a portion of a side hill road cut using, as at LOST CREEK, mounding and controlled blasting techniques and slurry explosive. (See Figure 10.) The detonation cut 320 feet of roadway using 8900 pounds of aluminized ammonium nitrate slurry. Figure 11 is presented to illustrate the results of the detonation prior to final mechanical excavation. Militarily this novel approach to road-cut excavation offers distinct advantages over conventional drilling and blasting in the areas of time, safety, equipment and manpower, and exposure to enemy action.

A primary objective of the continuing research effort being carried out by EERL is to reduce the cost and time of emplacing large chemical explosive charges in the ground and evaluating the sensitivity of the design factors affecting the drilling techniques for rapid explosive emplacement. To fulfill this objective, a study[4] is being conducted to provide a mathematical simulation model in the form of a computer code for explosive excavation design and to sequentially minimize the cost and time of the rapid emplacement of chemical explosives. The minimization procedure is based upon the simplex method of linear programming and the theories of chemical explosive excavation.[4] For cost minimization the simplex method requires a project cost equation in the form of a linear objective function which is minimized subject to a set of linear constraint equations. These constraint equations are derived using cost relationships that apply to the characteristics of explosive-produced craters. Such parameters as L/D (charge-length to diameter) ratios, media types, drilling methods (full-bore vs underreaming), charge size, explosive type, detonation characteristics, depth of burial, cratering volume effectiveness degradation, explosive costs, etc., are employed in the minimization procedure. In a similar manner, the time minimization requires a project time equation in the form of a linear objective function which is minimized subject to a set of linear constraint equations. This set of constraint equations is derived using time relationships that apply to the characteristics of explosive-produced craters.

A cost and time optimization code has been developed for single-charge cratering and has been used for a parameter study. For variations of the design parameters, determinations were made of L/D ranges at which various drilling techniques are cost and time advantageous. The results of this parameter study are represented in computer-generated plots similar to that in Figure 12. The design methods have been coded and currently the row-charge minimization model is being coded.

FY 73 RESEARCH AND EXPERIMENTAL PROGRAMS

The research and experimental programs for FY 73 will be directed toward the objective of investigating and evaluating the basic concepts and engineering criteria for using slurry explosives in the theater of operations. The majority of the research effort will concentrate on a literature search and consultation program with explosives manufacturers on the variety of chemical explosives available and those scheduled to be introduced, and on

Fig. 8 - Mound of Broken Rock Produced by Row Shot at Lost Creek, Oregon.

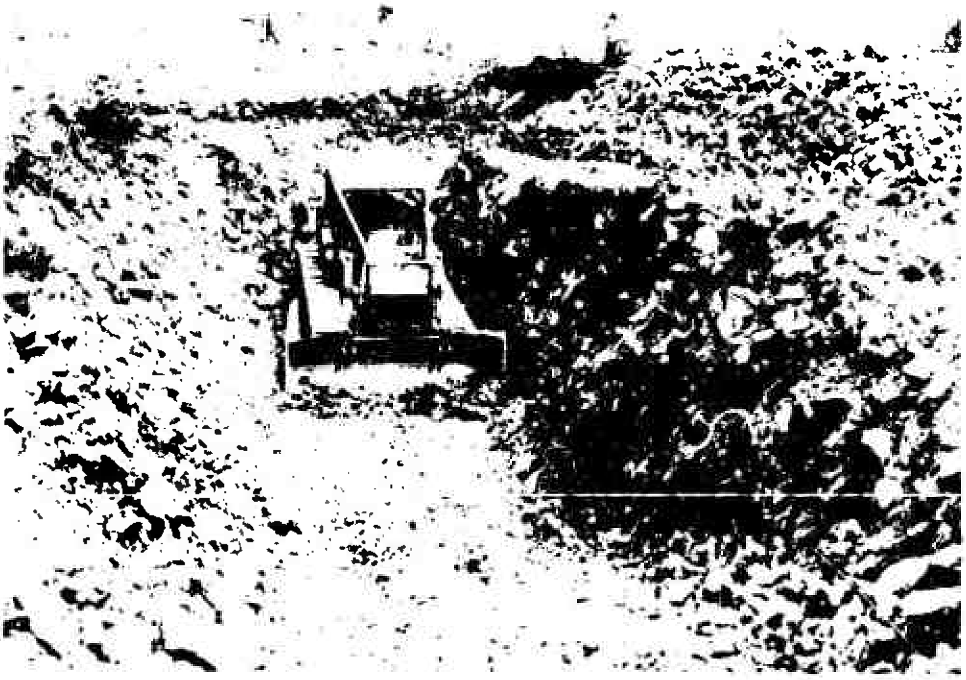

Fig. 9 - Partially Excavated Row Shot Showing Blast Rock Produced, Lost Creek, Oregon

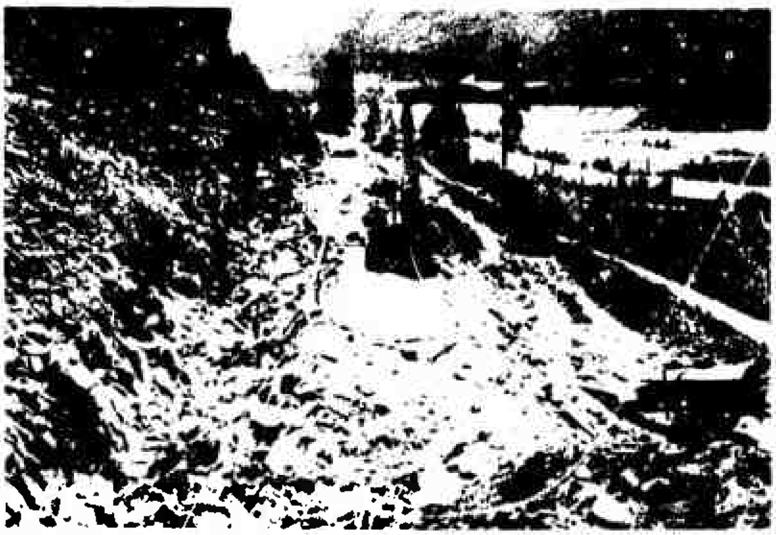

Fig. 10 - Drilling Section of Roadcut on Project LIBBY

Fig. 11 - Mound of Broken Rock Produced after Roadcut Blast, Project LIBBY.

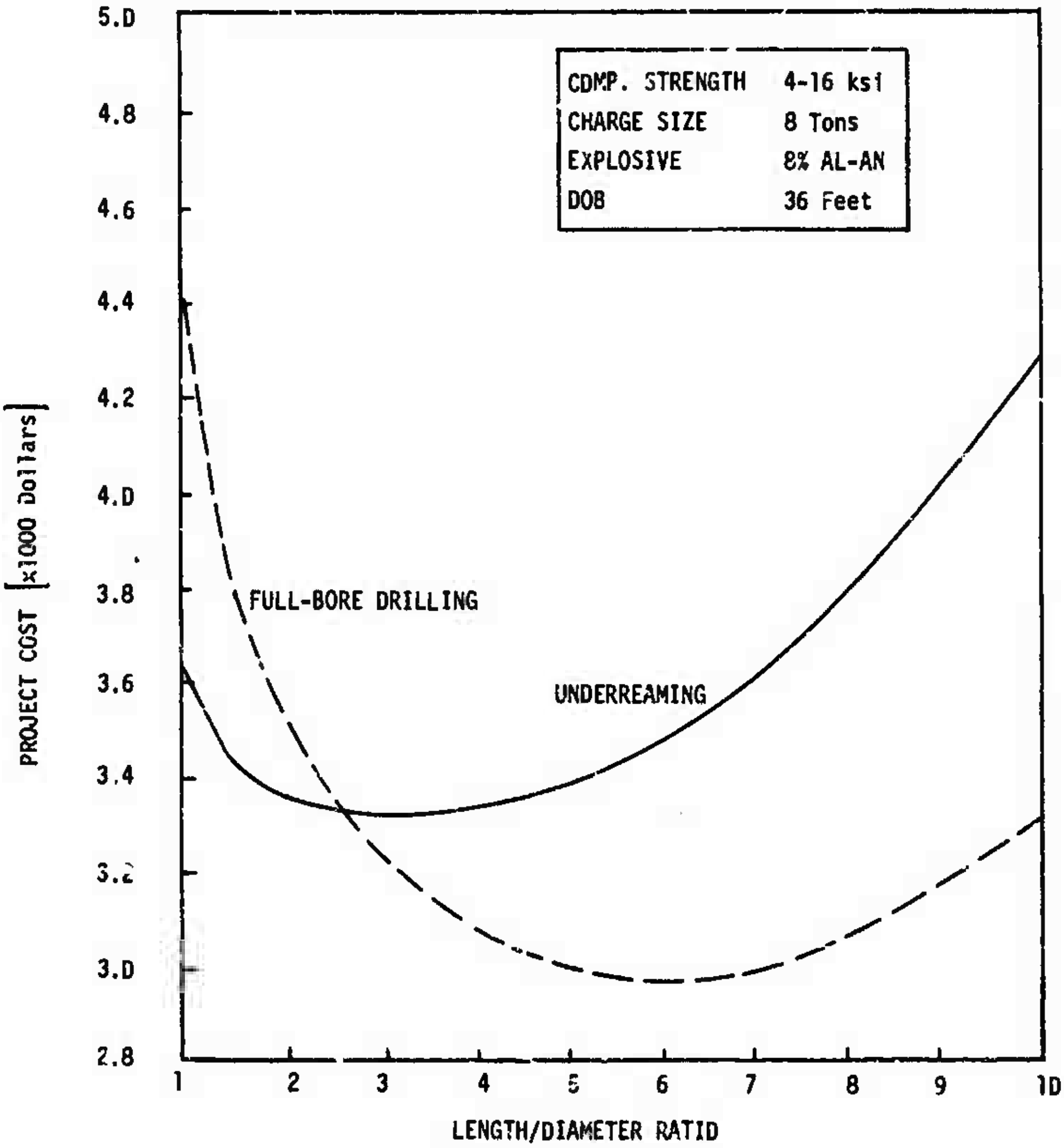

Figure 12. Minimum Project Cost Curves

the initiation of a parametric computer analysis of explosive effects. In addition, the emplacement computer analysis initiated in FY 72 will be continued to combine linear optimization of cost or time for the design of single- and row-charge cratering. Small- and full-scale testing of selected explosives, with emphasis on selection of the mixtures and designs for various military applications, will be conducted. The full-scale experiment called Project ARMOR OBSTACLE II will be conducted in conjunction with Project DIAMOND ORE which is also scheduled to be performed during October and November 1972 at Fort Peck, Montana. Project ARMOR OBSTACLE II, a series of cratering and mobility tests, is designed to evaluate and improve upon the Army's deliberate road crater and barrier techniques by using slurry explosives. The technical objectives of the project are as follows:

●To compare the cratering results of equivalent quantities of an aluminized slurry vs TNT in the same charge configuration in terms of crater dimensions and barrier effectiveness.

●To evaluate the handling requirements for loading and unloading both large and small quantities of slurry explosives in deep and shallow emplacement cavities.

●To evaluate the utility of a field-expedient explosive container for loading and unloading bag or bulk slurry explosives in deep holes.

●To determine in terms of crater dimensions and obstacle effectiveness the advantages of using slurry explosives to produce a Deliberate Road Crater (DRC) by comparing the cratering results of both identical and equivalent quantities of an aluminized slurry in plastic bags, 7 inches in diameter and 20 inches in length, vs 40-lb ammonium nitrate canisters.

●To test the feasibility of modifying the DRC design to accommodate slurry explosives in the same configuration with a view toward reducing the number of emplacement holes and the quantities of explosives required.

●To compare crater dimensions produced by a 40-lb AN canister vs a prilled ANFO canister of equal weight and approximately the same dimensions.

●To document with 16mm movies and still photography all explosive cavity construction, cavity loading and unloading operations, detonations, resulting craters, and mobility tests.

This project consists of three series of cratering experiments. A total of nine detonations will be performed with chemical explosives ranging in charge weight from 40 to 3960 lbs, buried in cavities ranging from 5 to 20 feet in depth. The major elements of the project are shown in Figure 13.

Each detonation in series I and II will be instrumented to measure airblast and seismic effects. Following the detonations, each crater will be measured by standard surveying techniques to determine the crater dimensions. The barrier effectiveness of the craters produced in these two series, as well as those produced in the DIAMOND ORE IIB Series (also scheduled for the same time frame), will be determined by each crater's ability to stop or impede the movement of a M-60 Main Battle Tank.

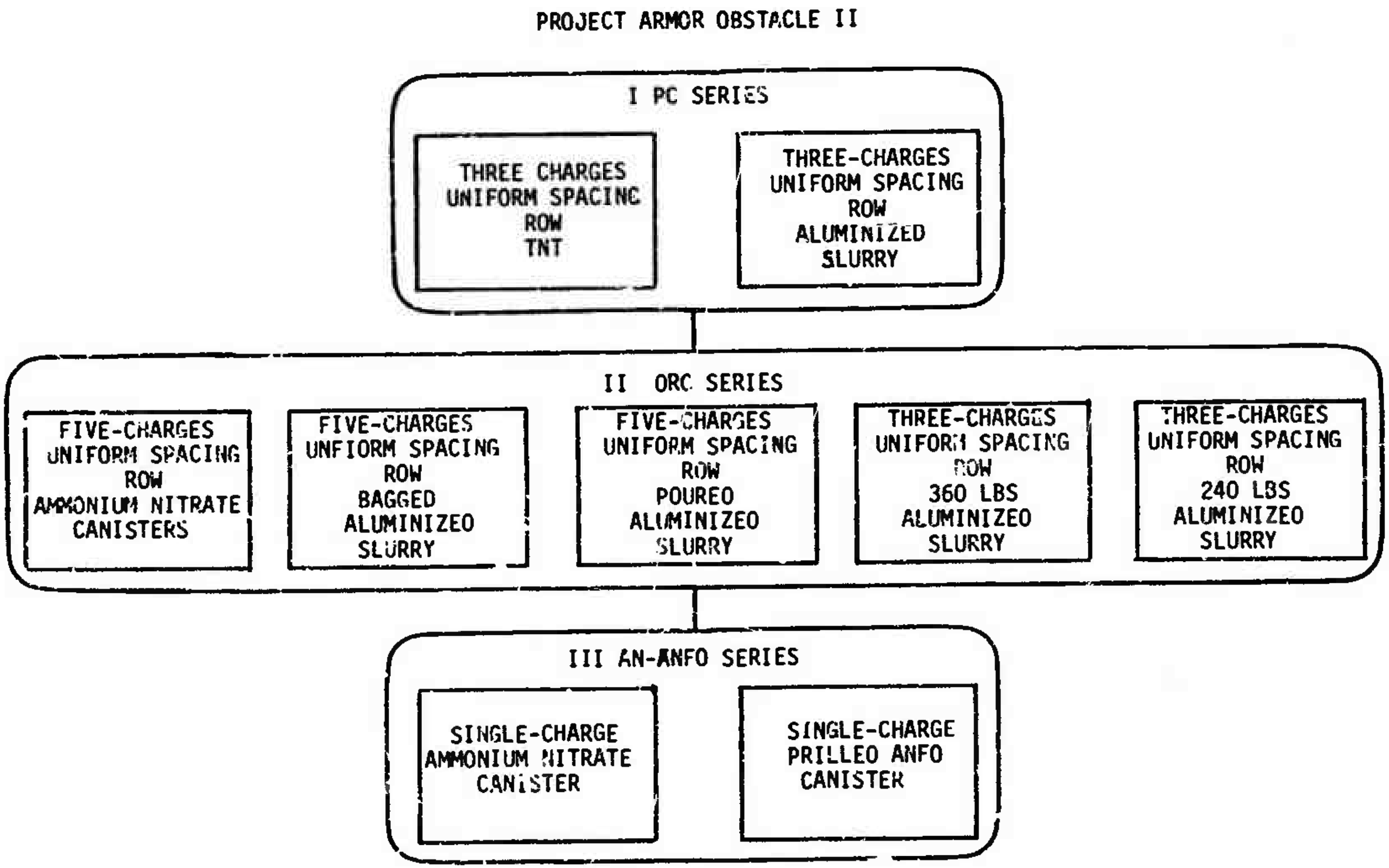

FIGURE 13. MAJOR ELEMENTS OF PROPOSED PROJECT ARMOR OBSTACLE II EXPERIMENTAL PROGRAM

In addition to testing the slurries utilized for the field experimental programs, EERL is planning to conduct a series of small-scale tests with slurries at the Lawrence Livermore Laboratory's Explosive Experimental Test Site (Site 300). The purpose of this program is to qualitatively evaluate a series of slurries as external charges. Using the procedures contained in Department of the Army Field Manual FM5-25, "Explosives and Demolitions," the TNT charge required to cut a steel plate of constant dimensions will be calculated and used as the standard base for comparison

Initially, a relative effectiveness factor as an external charge will be assigned to each slurry based on its detonation properties. This will be used for determining the amount of each slurry required to cut the same steel plate. Based on these results, the slurry charges will be varied to develop a complete picture as to their effectiveness as steel cutting charges. Depending on the results of these tests, additional work is contemplated in determining the effectiveness of the slurry against concrete and timber.

PROPOSED 5-YEAR PLAN

The 5-year chemical plan entitled "Engineer Criteria for the use of Chemical Explosives"[5] recognizes a need for improved Army explosives. Slurry explosives have demonstrated their applicability, effectiveness and versatility for commercial, Civil Works, and limited military applications. The information gained from these demonstrations had been integrated to develop the proposed research plan which is addressing the feasibility of slurry explosives as a military engineering tool. For the theater of operations the overall objective of the plan is to develop engineering criteria and employment procedures for the design and execution of Army Combat engineering missions through the use of chemical explosive excavation and destruction techniques. This comprehensive objective has been divided into several specific objectives as shown in Table 4.

The proposed 5-year plan is divided into three major areas which will evaluate the potential of slurry explosives for future military applications such as creating barriers, target destruction, and construction. These three areas are:

1. Explosive and Emplacement Rig Selection

2. Cratering and the Associated Effects

3. Application Experimentation.

Using chemical high explosives in the construction of engineer facilities in the theater of operations is a viable concept which could possibly result in major savings in time and logistical effort for the commander. There is nothing stated in Army Doctrine regarding the use of large chemical high-explosive charges for military construction. Therefore, it is imperative that the knowledge currently available be incorporated into Army Doctrine in order to allow construction project planners the additional option of employing chemical high explosives.

The feasibility of using chemical explosives for quarry construction has been demonstrated by industry Due to the limited testing that has been

Table 4

Objectives of 5-Year Plan

(Extracted from Chemical Plan)

III - 1.a	(1)	Analytical Solution for Chemical Explosive Selection
	(2)	Chemical Explosive Design for Demolition Munitions
	(3)	Liquid and Slurry Explosives Cratering Evaluation
	(4)	Handling and Shelf Life of Explosive Compositions
	(5)	Evaluation of Emplacement Considerations
III - 2.a	(1)	Cratering Phenomena
	(2)	Ejecta Phenomena
	(3)	Ground Shock Phenomena
	(4)	Airblast Overpressure
	(5)	Wave Action and Water Shock Phenomena
III - 3.2	(1)	Barrier Applications
	(2)	Field Fortification Construction
	(3)	Quarry Construction
	(4)	Construction of Cuts for Roads, Waterways and Harbors
	(5)	Hard Target Destruction
	(6)	Field Fortification Destruction
	(7)	Bridge Response to Explosion-produced Water Column

performed, essential parameters such as ground slope and depth of burial are not known to be truly optimum. In addition, a more thorough geologic dependency should be defined if its effect is significant. To accomplish this goal of constructing a quarry with chemical explosives, the proposed testing program should be performed to include: (1) an evaluation and feasibility study of work to date concerning quarrying with large charges to include a recommendation for a comprehensive testing program, (2) a testing program using chemical explosives to adequately define the parameters that are in question, and (3) the construction of a quarry using large chemical explosive charges.

The employment of chemical high explosives against hard targets and field fortifications is an area of research that must be investigated in order to give the field commander options which are not now available to him.

In the development of this proposed research plan, chemical explosives have been considered primarily as a cratering weapon to be used as an alternative to the ADM family. The fact that the Army does not currently have the capability for rapidly creating explosives or munition emplacement shafts to deep burial depth was also a primary consideration.[6] Other basic effects considered were crater ejecta, ground/water shock and airblast. Without knowledge of explosive requirements and the basic effects, little can be done in estimating target response.

If a family of chemical high explosives is to be adopted and employed with an acceptable degree of confidence it is necessary to develop knowledge of the basic effects (cratering, ejecta and shock) of the weapon when used in typical battlefield environments (soil, rock, underwater, etc.). Similarly, target response data must be determined and provided in a usable form to the field commander.

Figure 14 illustrates how EERL anticipates accomplishing this task during the next four years or as soon as the plan has been approved. The objectives delineated for the various years correspond to those listed in Table 4. Funding requirements for FY 72 and 73 are presented in Table 5.

Table 5

Schedule and Funding (in $1000) for FY 72 & 73

	Project	FY 72	FY 73
1.	Explosive and Equipment Selection	50	150
2.	Cratering and Other Effects	0	0
3.	Barrier Design	0	0
4.	Target Destruction	75	75
5.	Quarry Construction	0	0
	Totals	125	225

Figure 14. Summary Illustration for Proposed 5-Year Plan

(Extracted from Chemical Plan)

	FY 72	FY 73	FY 74	FY 75	FY 76
DIAMOND ORE (ADM 5-Year Plan)	← Objectives III-1.a.(1-5); 2.a.(1-5; 3.a.(1-6) →				
EXPLOSIVE & EMPLACEMENT RIG SELECTION	← III-1.a.(3),(5)	← Objectives III-1.a.(1),(2),(3),(4), & (5) →			
CRATERING & OTHER EFFECTS			← Objectives III-2.a.(1-5) & III-3.a.(2) →		
BARRIERS			← Objective III-3.a.(1) →		
TARGET DESTRUCTION (Water Plume Bridge Destruction)	← Objective III-3.a.(7) →				
(Hard Targets)			← Objective III-3.a.(5) →		
(Field Fortifications)			← Objective III-3.a.(6) →		
CONSTRUCTION (Quarry)				← Objective III-3.a.(3) →	

The updated 5-year chemical plan was submitted to the Office of the Chief of Engineers on 14 January 1972 by the Director of the Waterways Experiment Station. After the plan had been reviewed, OCE acknowledged the fact that recent developments of gelled slurry explosives may offer several advantages over present explosives available to accomplish military engineering tasks. Despite the noted advantages, there still remain a number of questions related to commercial explosives and their associated hardware which must be addressed before OCE can recommend continuation of the 5-year plan and possible changes in our current explosive doctrine and material. Some of these questions are listed below:

1. What is the anticipated distribution of Military Engineering applications for explosives in a typical theater of operations?

2. What explosives systems are presently being used for these applications?

3. What other explosives systems can be considered for these applications?

4. What are the international standardization considerations?

5. With regard to each application, what are the relative merits of the present and potential explosives systems with respect to the following:

a. Suitability for a variety of explosives applications; i.e., cratering, demolitions and quarrying.

b. Initial procurement considerations; i.e., costs, special materials, the R&D involved, specialized equipment, the ability to buy or otherwise obtain the explosive outside the U. S.

c. Suitability for storage in Engineer Units vs Depot storage.

d. Requirements for transportation precautions, such as special handling, procedures and equipment.

e. Requirements for emplacement to include time, personnel, equipment.

f. Suitability for preemplacement.

g. Ability to retrieve or neutralize.

h. Environmental constraints, such as humidity, moisture, and temperature.

i. Priming and booster requirements.

j. Chemical stability.

k. Requirements for maintenance of the explosive and associated emplacement equipment.

1. Personnel training requirements.

As a result of our previous experience with slurry explosives we feel we may be one step ahead in answering a few of these questions. However, answers to the majority of the questions will require an extended period of study and research. We anticipate obtaining valuable information on the latest classification of slurry explosive transportation requirements at this conference. The Engineer Strategic Study Group has already rendered some assistance by providing input to our investigation in the form of a "Demolition Target Evaluation" based on the Barrier Map Model Study Report (BAMM) (S) completed by V Corps in June 1969. The evaluation provides a realistic scenario which can be used in making the study. OCE has recommended that USAEWES conduct a one-year investigation to provide the answers to the questions above. The funds shown in Table 5 will be utilized to conduct the requested investigation of slurry explosives and a portion of EERL's FY 73 laboratory and field experimental programs. The ultimate goal of the investigation will be to "determine what, if any, changes should be made to the material and methodology currently used by the U. S. Army in the applications of chemical explosives." It is hoped that these questions can be answered satisfactorily with the cooperation and assistance of industry and other governmental agencies.

SUMMARY

This paper has attempted to illustrate what the U. S. Waterways Experiment Station has done, is doing, and plans to do in its continual evaluation of slurry explosives for military applications. Above and beyond the experience gained from large-scale Civil Works projects with slurry explosives, we have also tested and evaluated slurry explosives as a military engineering tool. Initial emphasis has been on the effectiveness of slurries to create craters which would effectively impede the movement of enemy vehicular traffic. Project ARMOR OBSTACLE I serves as an excellent example of the effectiveness of that program. Within the immediate future we expect to conduct an experimental program comparing the existing military cratering explosive with a slurry explosive. The comparison of these explosives will be conducted within the current employment doctrine and in various conceptual configurations which we anticipate will prove more efficient While this program is a step in the right direction, it is limited in scope. Within the framework of the 5-year chemical plan, we anticipate evaluating the total impact that slurry explosives might have on current and future military explosive applications. Although there are still many questions which must be answered prior to the implementation of this plan, it may well be that a family of slurries, having a wide range of detonation properties, could be the explosives providing the new and safer blast for the battlefield of tomorrow as well as the construction sites of today.

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SENSITIVITY OF HIGH-ENERGY PROPELLANTS TO IMPACT AND THEIR AIR-BLAST OUTPUT

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ABSTRACT

An experimental program was conducted to determine the impact velocities required to initiate three different solid propellant types. A total of 65 plate impact tests were conducted, using an up-and-down procedure. Air-blast pressure and impulse measurements, framing camera diagnostics, and field evaluations were used to determine the extent and severity of the reactions. Impact velocities ranged from 690 to 1600 fps.

The paper describes the experiments and diagnostic procedures used in determining the sensitivity of the propellants.

1. INTRODUCTION

This paper describes an experimental investigation of the initiation of subdetonation and detonation reactions of three propellant types under conditions of laterally unconfined impact by a rigid flyer plate. The three propellants tested were a newly-formulated Aerojet high-energy propellant ANP-3413 and two reference propellants, Hercules' high-energy double-base FKM propellant and Aerojet's composite propellant ANB-3066.

This work was directed toward determining the types of reactions which may be sustained by the propellant when subjected to a relatively long duration but low pressure loading which would result from an accidental impact of a rocket motor. The overall objective was to determine the relative potential hazards associated with the impact of the three propellants. The parameters considered were impact velocity, propellant type, and case material. Steel and fiberglass case materials were tested.

The technique used to conduct these studies was chosen with the goal of simulating, in an idealized laboratory setup, the actual intended application for these impact sensitivity data; namely, the prediction of the response of large motors to impact. The experiments were also general enough so that the quantitative data obtained, characterizing the physical quantities involved in the impact initiation phenomena, may permit extensions to quite different applications.

Several different observation techniques were used to determine the severity of reaction of the impacted propellant. These were: (a) evaluation of the condition of the immediate test area and the steel witness plate on which the propellant tests during impact testing; (b) the use of a Fastax framing camera to determine the maximum diameter of the fireball produced by the reacting propellant; and (c) measurement of blast overpressure and positive impulse histories, with gauges at several distances from the reacting sample.

2. EXPERIMENTAL PROCEDURES

Data on the dynamic response of the propellants were obtained through a series of experiments arranged as shown schematically in Figure 1. A steel anvil 1 x 2 x 2 ft. was buried ground level. Two steel witness plates were set on top of the anvil and the laterally unconfined propellant sample was placed thereon. Each propellant sample had either a steel or fiberglass case material attached, with epoxy as shown. A steel driver plate 1 in. thick by 4 in. diameter was set in contact with the case material. In each experiment, the flat driver plate was propelled by the plane initiation of low density (1.0 or 1.2gm/cc) charge of tetryl explosive. Impact velocities ranging from 690 to 1600 fps were obtained by varying the density and the quantity of driver explosive and keeping the driver plate size fixed. A blasting cap, a small tetryl pellet, and an aluminum bridge initiated a plane wave in the driver charge.

The charges were located in the field next to two blast pads, as shown in Figure 2. The pads are concrete slabs 75 ft. long by 10 ft. wide. Pressure transducers were installed flush with the top surface of the slabs in mechanically-isolated steel plates. The plates cover a channel in which the gauges were installed. For these tests, eight gauges were mounted on the blast pads. Side-on overpressure was measured, and total positive impulse was electronically computed from four gauge stations.

High-speed Fastax and normal-speed Bolex cameras were used to record fireball size. Fiducial markers were located in their field of view.

Driver plate velocities were established, using high-speed photography techniques, in a separate set of experiments.

3. EXPERIMENTAL RESULTS

A total of 75 tests were conducted in the field to determine the sensitivity of the three propellant types and to calibrate the driver-plate system. Ten tests each were conducted with ANB-3066 and FKM propellant, with steel and fiberglass-case plates.

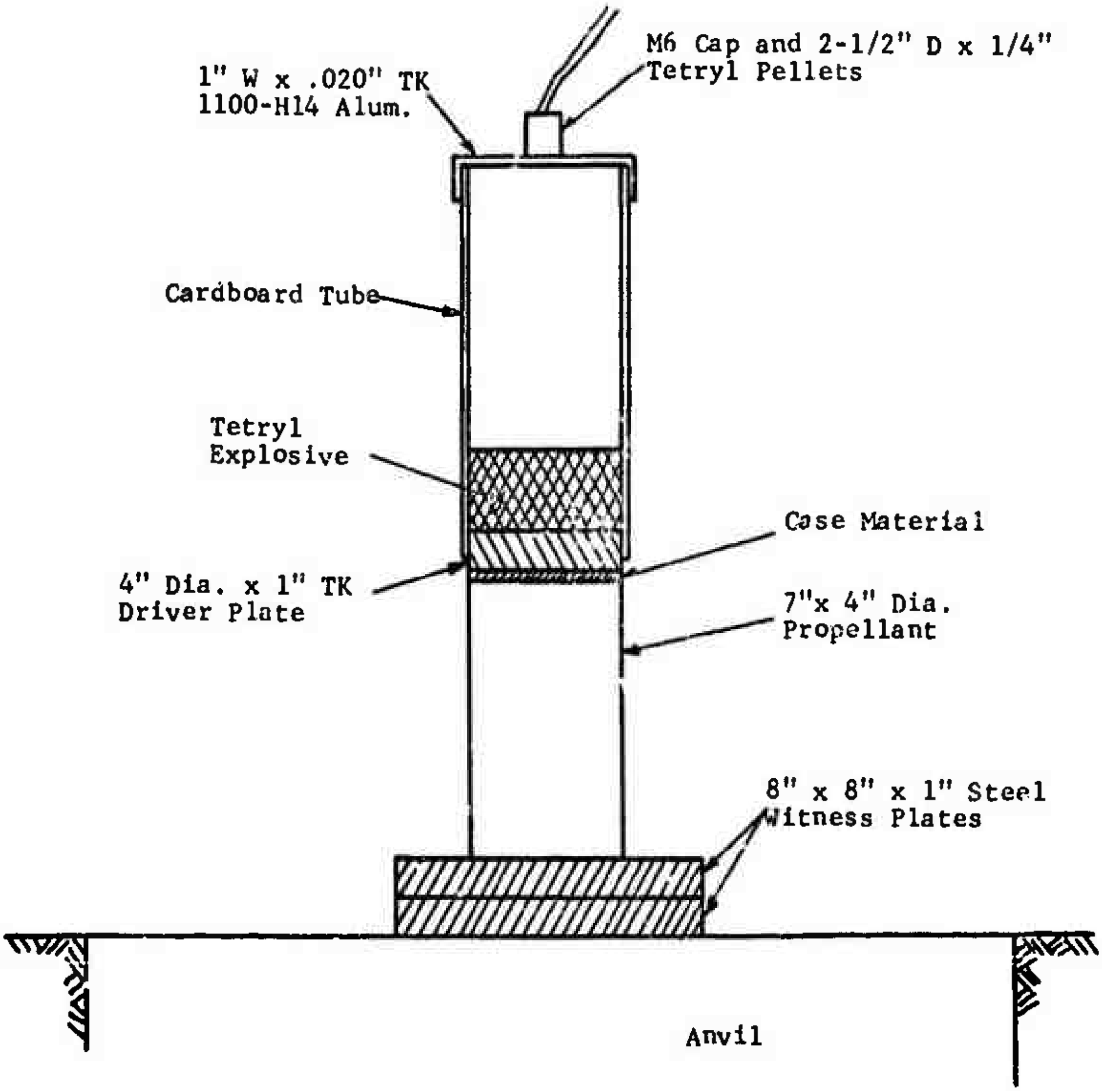


Figure 1: EXPERIMENTAL SETUP FOR IMPACT TESTS

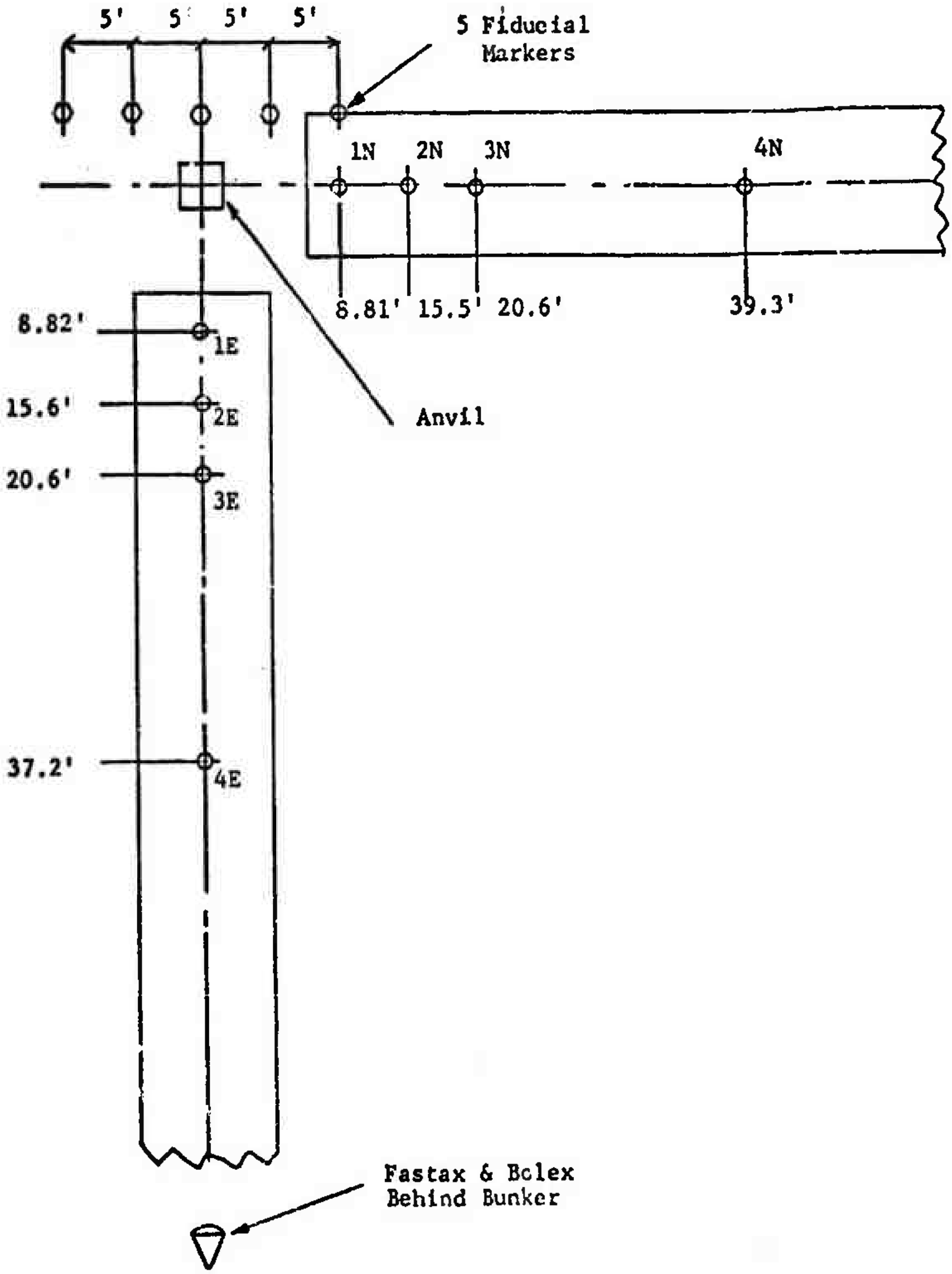


Figure 2: PROPELLANT TEST AREA

Twelve tests were conducted with the ANP-3413 fiberglass-case plate samples, and 13 tests were conducted with the ANP-3413 steel-case plate samples. In addition, 10 tetryl calibration tests were conducted to determine the effects of the driver explosion alone.

3.1 Propellant Reaction Criteria

Establishing a criteria (Reference 1) for propellant reaction is essential to determining sensitivity. The extent of a reaction was determined by post-test inspection of the test area and steel witness plate on which the sample rested during the impact test, the maximum diameter of the fireball produced by the reacting propellant, and the blast-overpressure history produced by the reacting propellant.

The firing proceeded as follows. The propellant was impacted at some velocity, after which the impact velocity was increased if the specimen did not react, and decreased if the specimen did react. The decision as to whether or not the propellant reacted was made immediately after the experiment, and was based on the appearance of the immediate test area.

The criteria established to evaluate the propellant samples is as follows:

<u>No Reaction</u>

No pressure/impulse output
Unreacted propellant post-test
Firebrands
No flash marks, dents, or spalls on the witness plate
Fireball the same size as the tetryl-only fireball

<u>Partial Reaction</u>

Some pressure/impulse output
Small quantitities of unreacted propellant post-test
Firebrands
Flash marks, but no dents or spalls on the witness plate
Fireball the same size as the tetryl-only fireball

<u>Consumed</u>

Pressure/impulse output
No unreacted propellant post-test
No firebrands
Flash marks, but no dents or spalls on the witness plate
Fireball is larger than the tetryl-only fireball

Detonation

Pressure/impulse output
No unreacted propellant post-test
No firebrands
Dented or spalled witness plate
Fireball is larger than the tetryl-only fireball

3.2 Field Evaluations

During each test, an observer was positioned in the field at a safe distance from the test location, to qualitatively judge the propellant reaction level. This included observing firebrands, fireball size, and loudness of the reaction. Extremes in the reaction level were readily discernable from observations of this nature.

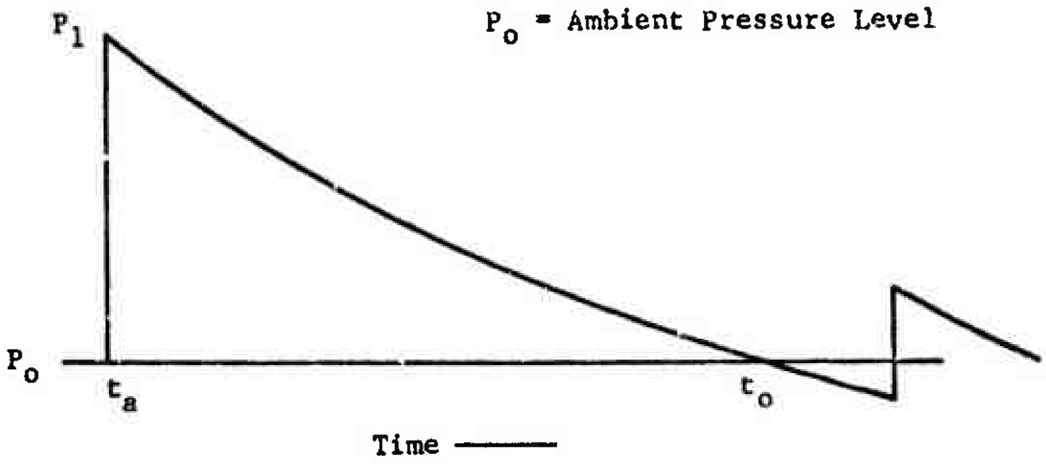
After each shot, the immediate test area was examined. The witness plates were recovered and examined for flash marks, dents, and/or spalls. Grass fires were noted and the area was examined for unreacted propellant.

3.3 Camera Diagnostics

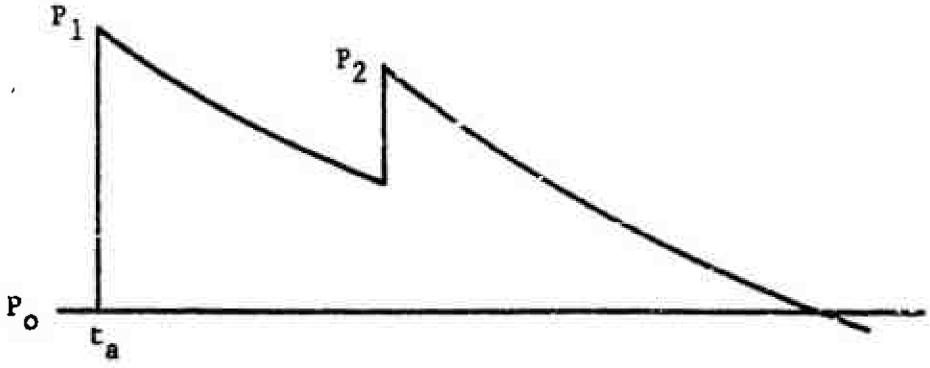
High-speed and normal-speed motion pictures were taken of each shot. The maximum fireball size was determined, and comparisons were made between the propellant and tetryl-only shots. The presence of firebrands was also noted and compared with observed field evaluations.

3.4 Pressure/Impulse Measurements

The pressure-time waveform, as recorded by a side-on pressure gauge for a tetryl detonation, is illustrated in Figure 3a. It consists of a sharp pressure rise, shock front, to some pressure P_1 whose value is dependent upon the tetryl charge weight and the radial distance from the charge. The pressure wave exponentially decays to ambient pressure at time t_o. The area under this portion of the pressure-time curve is called the positive impulse of the pressure wave and appears as a shaded area. After time t_o, the pressure becomes slightly negative and relatively weak after shocks occur which travel backward. These aftershocks become



a. Tetryl Test



b. Reacting Propellant Test

Figure 3: TYPICAL PRESSURE-TIME RECORDS

weaker and more delayed as the radial distance is increased.

The pressure-time waveform for a test wherein the propellant reacted is illustrated in Figure 3b. The first peak P_1 is the shock front from the tetryl driver charge and its magnitude is dependent only upon the tetryl charge weight and radial distance. The second pressure pulse P_2 is a measure of the reactivity of the impacted propellant.

When the tetryl driver charge is detonated, it immediately generates a blast wave P_1 which propagates radially from the charge. Some finite time later, the driver plate impacts the propellant specimen, and if the propellant reacts, it generates a second blast wave P_2, which follows behind the first wave. In essence, the phenomenon is that of two sequentially detonating explosive charges (Reference 2); the second blast wave travels faster than the first and, in some instances, actually catches up with the first shock wave within the radial measurement distances of these tests. As the radial measurement distance is increased, the Δt valve between the two shock waves decreases.

The value of P_2 is dependent upon the reactivity of the propellant, propellant weight, radial distance, and impact velocity. Propellant reactivity and impact velocity are, of course, interrelated. Positive impulse is the shaded area under the pressure-time curve. When no propellant reaction occurs, the pressure wave measured is the same as if only the tetryl driver had been detonated in the test setup.

3.5 Summation of Experimental Results

Typical results of these experiments are summarized in Table 1, and are illustrated in Figure 4. The table indicates the following occurrences for each test: a measurable increase in pressure and impulse; unreacted propellant in the area post-test; firebrands; flash marks on the witness plate; dents or spalls on the witness plate; and a larger fireball than that occurring with the same size tetryl driver charge only. Each test is rated, and the reaction level of the propellant sample is determined by the

Test No.	Impact Velocity, fps	Pressure/Impulse Measurement	Unreacted Propellant Found	Firebrands	Flash Marks on Witness Plate	Dented Witness Plate	Spalled Witness Plate	Fireball Larger than Calibration	Propellant Sample Reaction				Comments
									U	P	C	D	
ANP-3413/F- 1	690	No	Yes	Yes	No	No	No	No	X				Unreacted Propellant on Witness Plate
- 8	690	No	Yes	Yes	Yes	No	No	No	X				Unreacted Propellant.
- 2	940	Yes	No	Few	Yes	No	No	Yes			X		
- 7	940	Yes	No	Yes	Yes	No	No	Yes		X			
- 9	940	Yes	No	Yes	Yes	No	No	Yes		X			
-11	940	Yes	No	Yes	Yes	No	No	Yes		X			
- 3	1080	Yes	No	Yes	Yes	No	No	Yes		X			
- 6	1030	High	No	No	Yes	Yes	No	Yes				X	
-10	1080	High	No	No	Yes	Yes	Yes	Yes				X	Witness Plate Spalled
-12	1080	Yes	No	No	Yes	Yes	No	Yes			X		
- 4	1370	High	No	No	Yes	Yes	Yes	Yes				X	Witness Plate Spalled
- 5	1600	Yes	No	No	Yes	No	No	No			X		

Table 1

ANP-3413/F Propellant Test Summary

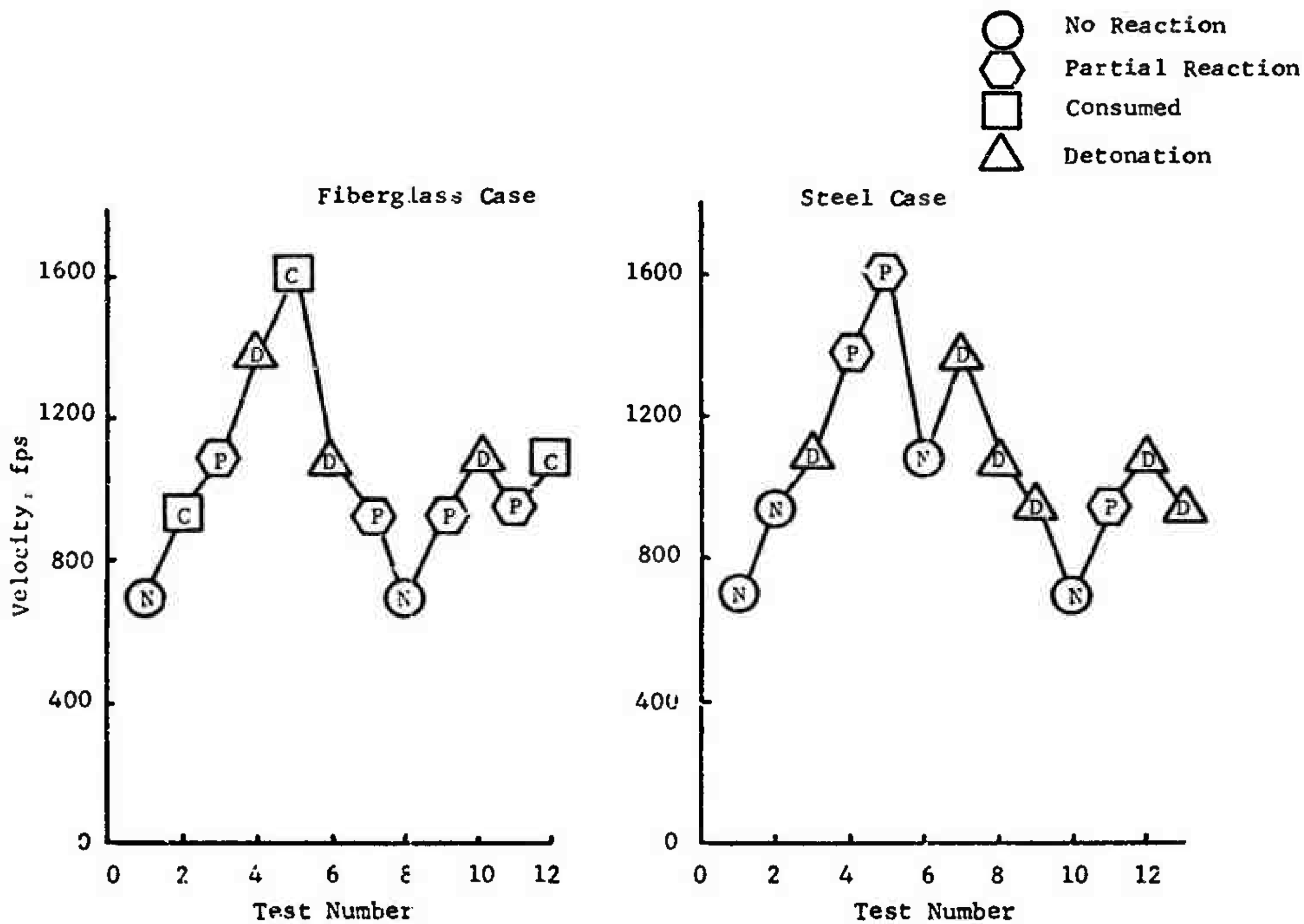


Figure 4: TYPICAL GRAPHICAL TEST SUMMARY

criteria established in Subsection 3.1.

3.6 Bruceton, Up-and-Down Analysis

A Bruceton or up-and-down analysis (Reference 3) was performed for each propellant sample type. Based upon the propellant reaction levels determined in Table 1, percentile velocities tabulated in Table 2 were determined. The analysis implies that 50 percent of the time the propellant sample will respond at the reaction level indicated when subjected to the respective impact velocity.

Note that some overlapping occurs between the consumed and detonation reaction mean values. This is partially explained by: (1) it is possible to over-impact a propellant and cause it to under-react*; and (2) in order to obtain a true statistical average, many more tests would have had to be performed than the limited number herein. These average impact velocities do, however, serve as ballpark estimates of the sensitivity levels of the propellant samples. Table 3 illustrates the lowest impact velocity at which a reaction occurred.

*At high impact velocities, the propellant is subjected to a high-pressure shock wave similar to that produced by the gap test. It has been shown (Reference 4) that composite propellants cannot be ignited when subjected to high pressures as in the gap test. Under these conditions, the material generally shatters. However, when the initial pressures are low, as occurs during low-speed impact, when large deformations occur, the propellant is readily initiated by a crushing mechanism.

Table 2

FIFTY PERCENT PROBABILITY OF REACTION IMPACT VELOCITY

Propellant Sample	Partial Burn	Consumed	Detonation
ANB-3066/F	1060	--	--
ANB-3066/S	1060	--	--
FKM/F	940	1150	--
FKM/S	1060	1170	1490
ANP-3413/F	890	1130	1040
ANP-3413/S	1110	960	1020

Units: fps

Table 3

LOWEST IMPACT VELOCITY FOR REACTION

Propellant	Partial	Consumed	Deconation
ANB-3066/F	960	> 1600	> 1600
ANB-3066/S	960	>1600	>1600
FKM/F	960	960	>1600
FKM/S	960	960	1370
ANP-3413/F	960	960	1080
ANP-3413/S	960	1080	1080

Units: fps

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SAFETY ASPECTS OF CONTAINERIZED ORDNANCE

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Earle, N. J.

1. Introduction

Containerization has had a phenomenal effect on all modes of transporting cargo. The most dramatic effect has been the rapid change in the U.S. Merchant Fleet. Literally billions of dollars have been invested in new ships and port facilities, which have revolutionalized a dying industry into one of the world's finest fleets. Containerization has changed a labor intensive industry, which was becoming increasingly non-competitive, into a capital intensive industry which leads the world in containerized shipping. The shipping industry has become increasingly dependent upon containerized cargo as new containerships are launched, break bulk ships are converted to carry containers, and the older break bulk ships are scrapped or mothballed. The Armed Services make up one of the leading cargo generating sources and have always been dependent on our Merchant Fleet to ship cargo to troops located throughout the world. In order to continue this dependent relationship, the Armed Services must be capable of containerizing both supplies and ordnance in order to dove-tail with the Merchant Fleet.

Dry goods and supplies have been successfully containerized by the military. Containerized military cargo has been used extensively in shipping to Southeast Asia, which has resulted in significant reductions in shipping costs. The bulk of this cargo has been handled under contracts including dour-to-door delivery through U.S. commercial ports. Unfortunately, the transition of shipping ordnance in containers has not met with equal success.

There are many problems involved with setting up a containerized distribution system and these problems are multiplied when dealing with ordnance. The inherent nature of explosives imposes restrictions and precautions creating special problems which must be overcome. The most significant of these is the need for developing containerized ports at military activities both in CONUS and overseas since commercial ports are barred from handling explosives.

2. Advantages of Containerized Shipping

There are several economic advantages that have led commercial industry to adopt containerized shipping. The ability of containers to be shipped by all modes of transportation without the need for rehandling the contents reduces both labor and time for throughput shipments. Shiploading can be reduced by as much as a factor of 10 which decreases the ship's turnaround time and increases the throughput from port facilities. The container offers greater protection from damage and pilferage which in commercial practice has reduced insurance rates.

Relating these advantages to containerization of ordnance means reduced response time and costs in shipping explosives throughout the world. The greatly reduced number of handlings should of course reduce safety problems significantly. The handlings that do occur are automated to a large degree which reduces the possibility of human error or carelessness. The container offers greater security in shipments that should reduce both physical damage and the possibility of tampering.

3. Safety Aspects

Although containerized shipping of ordnance offers many safety advantages over break bulk shipping, there are several safety problems that

have not yet been resolved and have in fact presented stumbling blocks to an efficient containerized distribution system. The greatest problem has been that the rules and regulations governing handling, shipping and storage of ordnance have been written for conventional break bulk techniques, and the difficulty arises in trying to apply these rules to containerization. As of yet, few regulations have been written which would apply directly to containerized ordnance. Instead, arbitrary decisions as to interim procedures have been set up which may or may not be realistic.

One of the problems that is likely to occur in the future is that of exceeding quantity distance requirements. Containership capacities have grown to over 2000 twenty-foot units. Based on a net explosive content of 40%, even a 1000 unit containership would have a total quantity of 14,000,000 lbs of explosive which far exceeds any pier facility available. Because of the fast turnover rate of a container berth, similar quantity problems will also exist in backup storage facilities.

Because containers are intermodal, their loading, blocking and bracing must meet the most stringent regulations of highway, rail, and ocean transportation. This means there are three sets of safety regulations set up by the Department of Transportation, the American Association of Railroads-Bureau of Explosives, and the Coast Guard that must be met. These regulations are in some cases contradictory.

One example of this overlap would be the marking or placarding of MILVAN's. For highway movement, an explosive placard with the DOT class is required, for rail shipment a placard with a warning to keep fires and lights away, and for ocean voyage the rail warning and the Coast Guard class

are required. It would certainly be advantageous to have one system of marking so that the container could be moved intermodally without changing placards.

For highway movement there are no new instructions for containers and one would use those that would apply for trucks. The principle limitation is that of weight allowable in the particular length of the rig used to haul containers. Either standard commercial container or Army MILVAN containers equipped with belt rails and cross-members could be used equally well.

The safety regulations for rail shipment vary somewhat for containers. As of yet, no commercial intermodal containers have been used for explosive shipments by rail while Army MILVAN containers are approved for both container-on-flatcar- (COFC) and trailer-on-flatcar (TOFC). The belt rails and cross-members are used to provide bulkheads in the front, in the rear, and in-between pallet loads of ordnance. During rail impact tests that are required to qualify MILVAN's and particular loading patterns, the cross-members absorb the shock and keep the loads from applying force to the end walls. Therefore, commercial containers at present cannot be used for either COFC or TOFC shipments of ordnance. This imposes particular constraints on the Navy which is dependent on the Army to supply MILVAN's which are not in over-abundant supply and usually require costly movements to preposition at inland stuffing activities. This was the justification for using commercial containers in the shipment of 525 containers last year, which required costly double handling or unloading railcars and stuffing containers at the port.

The Coast Guard has imposed stringent regulations on containerized shipments to compensate for the lack of provisions in the Code of Federal

Regulations. Perhaps the most costly of these regulations is the requirement of vertical blocking and bracing also called tomming which must be capable of withstandingup to a 2g vertical force. Both the Navy and Army are attempting to eliminate this regulation since it has doubled the cost of loading, blocking and bracing ordnance containers. Some of the arguments have been that tomming is not required for truck or rail shipments which have been found to be more rigorous modes of transportation than ocean voyage, and tomming is not even used on break bulk ships for normal palletized loads. A container offers a smaller, better secured compartment for cargo than an entire hold of a break bulk ship, yet the CG has set far more stringent blocking and bracing requirements for containers. The Naval Weapons Handling Laboratory has conducted several tests of instrumented containers both with and without vertical blocking to obtain further information on this subject.

The Coast Guard has also limited the cargo carrying capacity of commercial containers, vis-a-vis Army MILVAN's, to 80% of the net payload. This requirement, coupled with the low cube utilization of dense ordrance cargo, which tend to weigh out the container long before the container is filled, limits the cost effectiveness of commercial containers severely. Another requirement is that sample loads of these commercial containers loaded to 100% capacity must be tilted 80^{o} on their sides. Simulating ship rolls of 80^{o} appears to be unrealistic at the least.

Containerships tend to be more difficult to design stowage plans for than break bulk ships. They are usually divided into a few large holds without any bulkheads. This imposes many problems in separating various classes of ammunition to comply with Coast Guard regulations. To date, the

the Coast Guard has allowed mixing classes within one hold when incompatible classes are separated by a layer or row of inert or empty containers. However, this has created additional problems for proper ship stowage plans. The lighter containers loaded with inert items such as bomb fins should properly be stored on deck to enhance ship stability, but are required below deck as separators.

Perhaps with information gained by propagation tests, we will be able to present evidence to the Coast Guard that each container or MILVAN can be treated as a separate hold in the ship. This would completely eliminate all stowage problems, but will probably not come to pass. However, we may discover that a container or MILVAN will offer sufficient separation for some classes of explosives.

The Coast Guard has also imposed some limitations on the types of explosive classes that may be deck loaded in containers which further complicates ship stowage plans.

One area that has received little attention is that of heat build up within Army MILVAN's which are not vented. The Naval Weapons Handling Laboratory is currently conducting instrumented tests to record temperatures in MILVAN's with and without reflective paint on the roofs.

Although none of these problem areas or restrictions has made container shipments of ordnance impossible, they have not all been shown to increase safety and have added additional costs which have frustrated attempts to show a cost effective system. It is hoped that in an attempt to be overly safety conscious with these early containerized ordnance shipments, we do not add needless burdens to the economics of this shipping mode and destroy a system that inherently offers numerous safety advantages.

TOOELE CONTAINER PROPAGATION TESTS

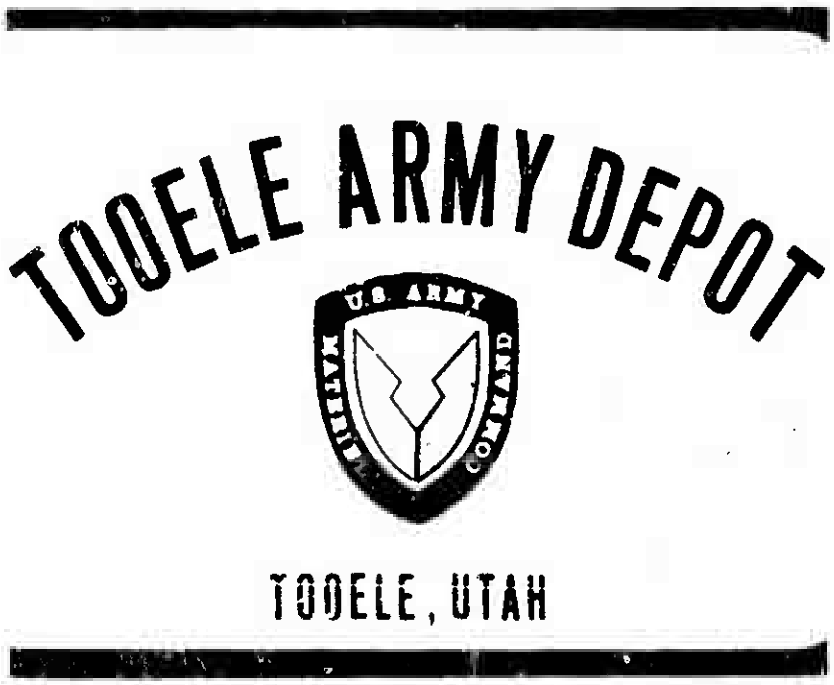
Mr. F. H. Crist
Tooele Army Depot
Utah

ABSTRACT

Summary of a series of container propagation tests performed for the DOD Surface Container Systems Project Office. The purpose of these tests was to evaluate the prospect of separating MILVAN containers of Class 7 ammunition items within a containership in such a manner that a fully loaded containership would not have to be totalled for quantity-distance purposes. Secondarily the results have a bearing on compatibility problems with regard to the storage of ammunition in containerships which cannot comply with the existing Coast Guard regulations for compatibility between holds or within separate holds of breakbulk ships. Movies of specific tests and summary of the results will be included.

Slide #1 (TEAD Slide)

Good Morning Gentlemen. My presentation covers a series of tests being conducted near the famous Bonneville Salt Flats of Utah. The purpose of these tests is to determine the feasibility of minimizing the propagation of a detonation through an ammunition stuffed Milvan container ship, but like the assigned quests of The Princes of Serendip, many new unsought facts and surprises about the behavior of ammo have been discovered.

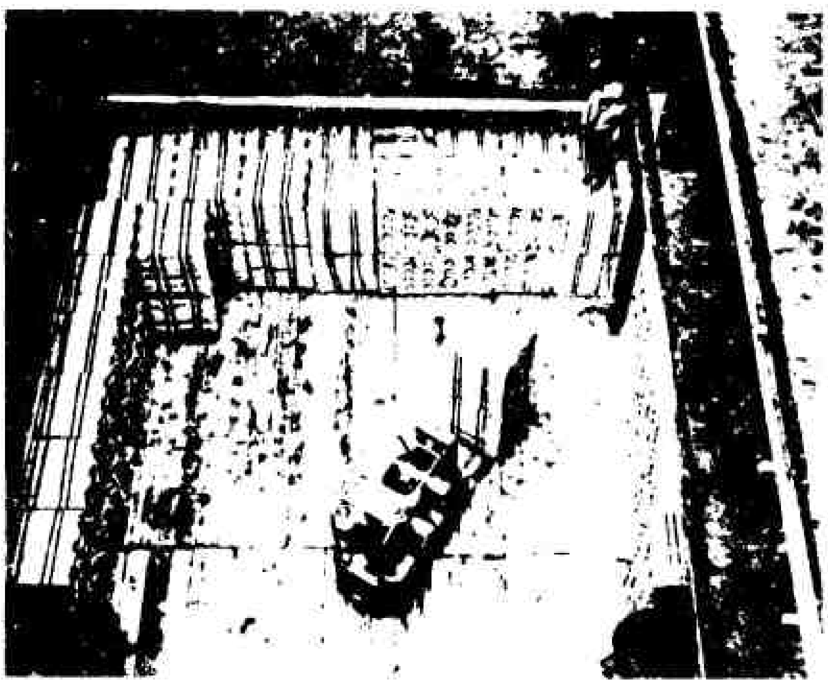


Slide #2 (Break Bulk Cargo Ship)

This first series of slides are for the benefit of "landlubbers", like myself, who are not intimately familiar with the difference between "Conventional" and "containerized" ammo shipments. This specific slide depicts palletized ammo ready for loading into one of the holds of a cargo ship.

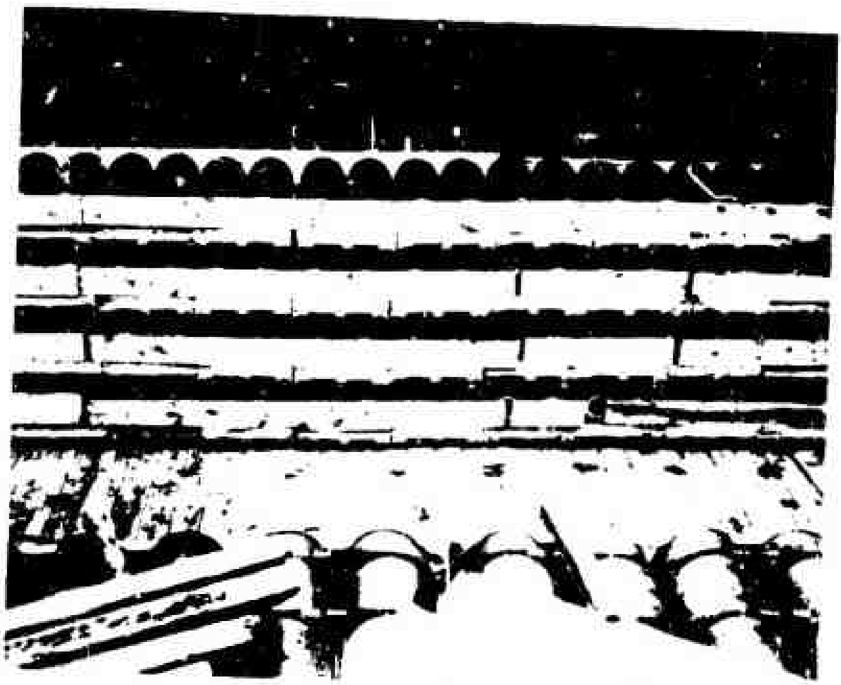
Slide #3 (Boxed Ammo Between Decks)

This slide depicts boxed ammo stowed between decks in one of the ship's holds.



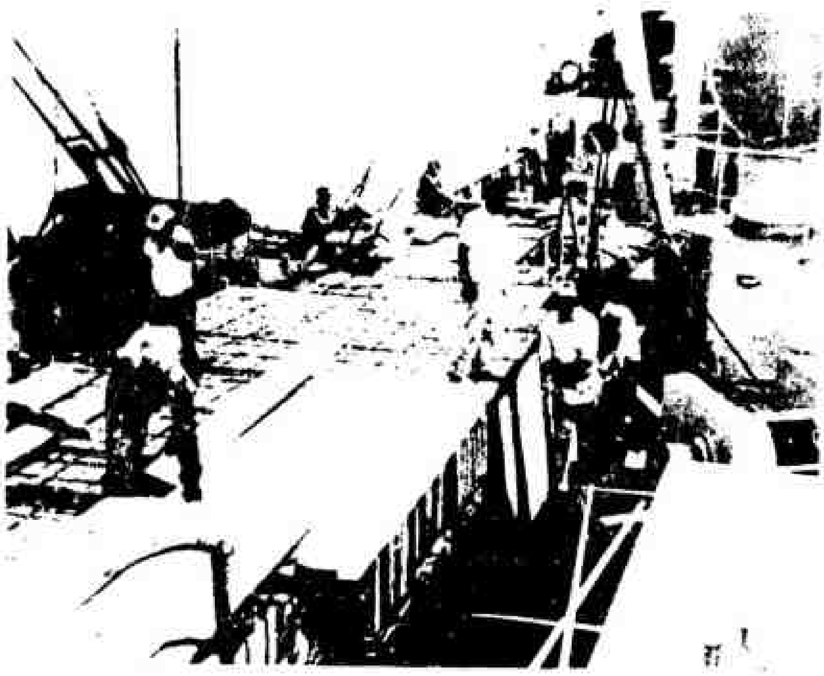
Slide #4 (Bombs Stowed Between Decks)

This is a between decks view of bomb stowage.



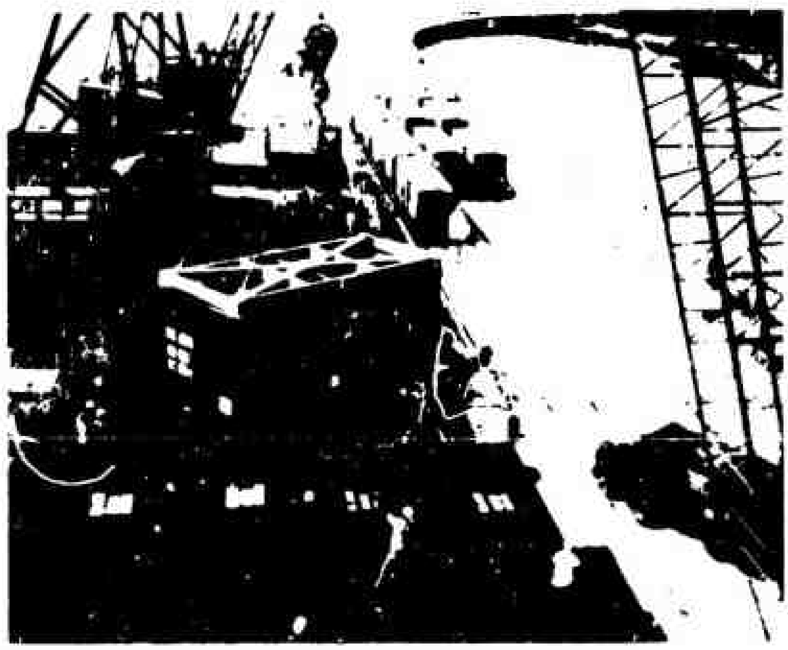
Slide #5 (Boxed Ammo Above Deck)

As shown by this slide, boxed ammo is also stowed above decks.



SLIDE #6 (Milvans Being Loaded Aboard Ship)

One of the most interesting developments of modern times is the formation of joint union and management committees assigned to improve the productivity of our basic steel industry. Both labor and management acknowledge the truism that only thru increased productivity per man hour expended can foreign competition be met, real wages be increased and the bountiful life, goal of all American families, be achieved. The use of Milvan containers for movement of ammunition from the manufacturing plant or storage location to the requisitioner is expected to dramatically improve the military track record in the handling of ammunition.

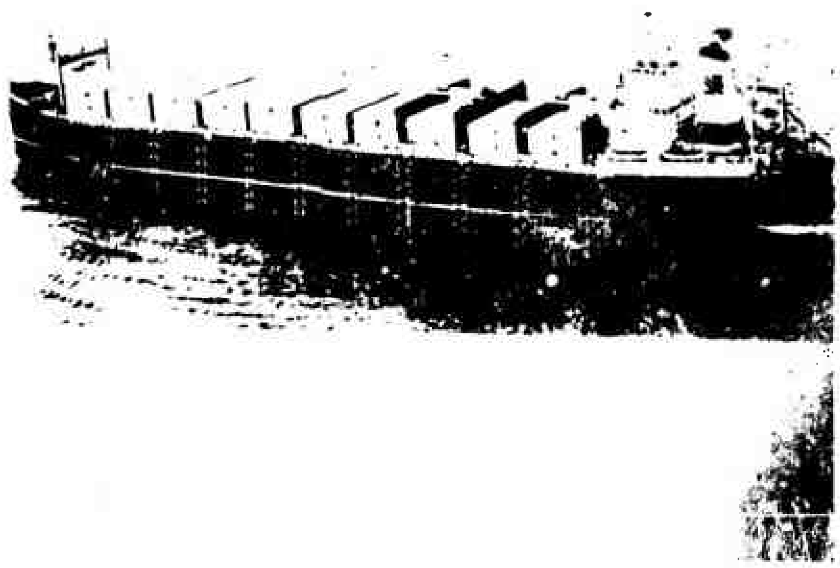


SLIDE #7 (Milvans Being Loaded in the Hold)

This slide depicts the stowage of Milvans below deck. Note the conspicuous reduction of blocking and bracing required to secure the cargo.

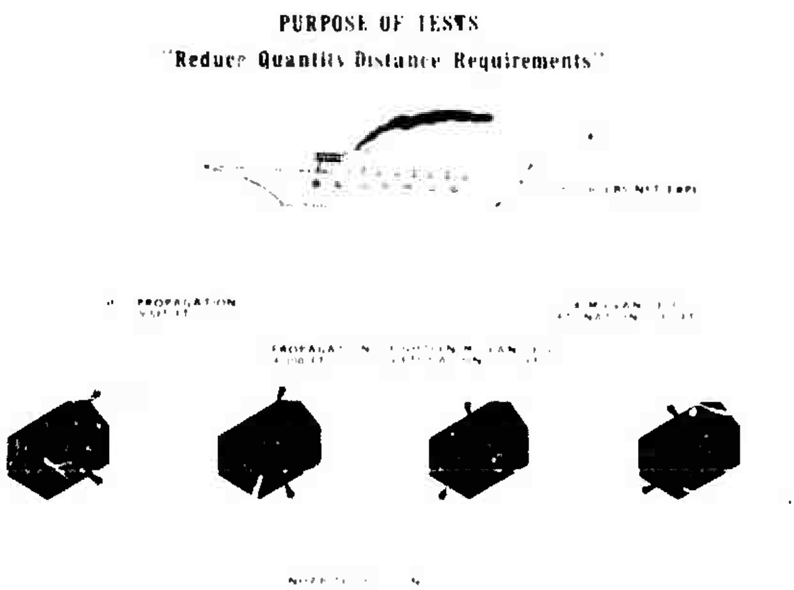
Slide #8 (Milvan Loaded Ship at Sea)

Another dilemma being faced by this country is our exorbitant expenditure of fossil fuel reserves. Utilization of large container ships, as shown by this slide, should not only improve our productivity for each seaman manhour expended but should also stretch more knots from our dwindling fuel reserves.



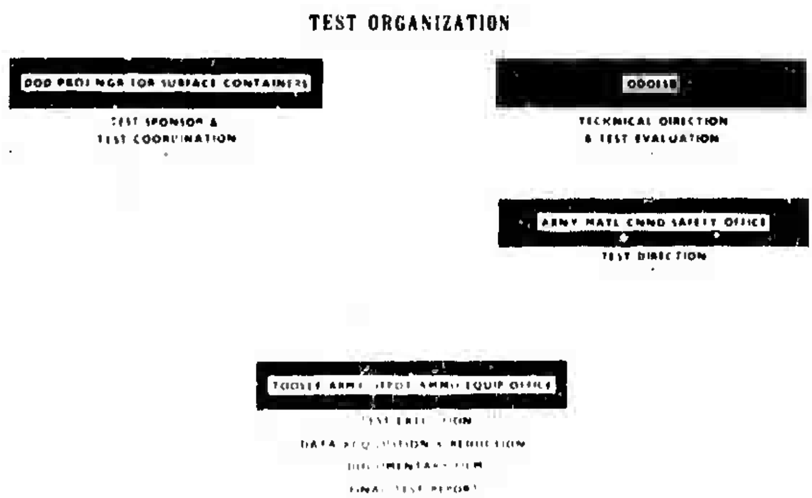
Slide #9 (Purpose of Tests)

The price to be paid for productivity increases and conservation of fossil fuel is the amassing of explosives which in aggregate exceed available safety zones of the worlds ports. The purpose of our tests is therefore to determine the feasibility of checkerboarding less energetic (Class 4 or lesser) munition stuffed Milvans between cells of mass detonating (Class 7 or above) munition stuffed Milvans. Our immediate goal is to provide stowage options that will limit mass detonating munition stuffed containers to isolated cells of 18 or less containers (248,000 Lbs. HE).



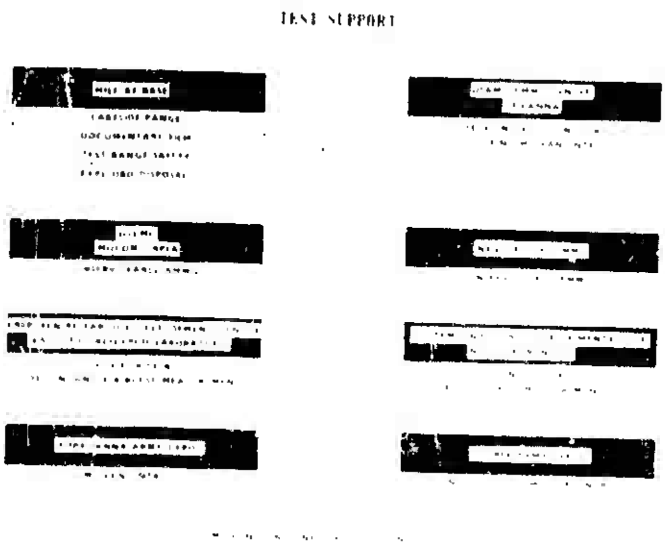
Slide #10 (Test Organization)

As shown by this slide, the DOD Project Manager for Surface Containers is the test sponsor and coordinator. The DODESB designed the test plan and established the test result evaluation criteria. Specific test direction has been provided by the AMC Safety Office to the Ammunition Equipment Office of Tooele Army Depot.



Slide #11 (Test Support)

The activities identified on this slide either participated or provided material or services required for the execution of the test. These tests made a considerable dent in the Army and Navy FY 72 demilitarization workload. A considerable monetary savings was realized by the substitution of unserviceable Milvans in lieu of new containers.

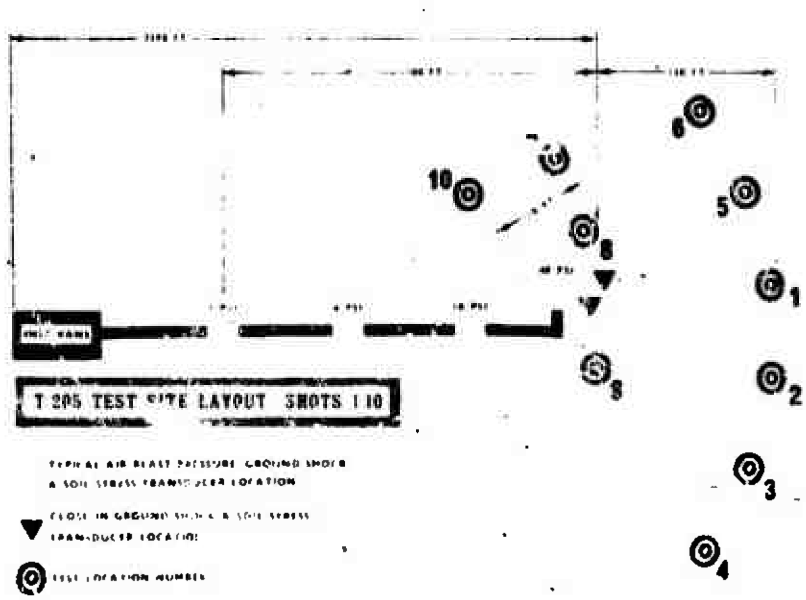


Slide #12 (HAFB Test Facility)

The Lakeside Test Range operated by Hill Air Force Base was selected for accomplishment of the container propagation tests. The specific site selected was previously utilized for the Air Force Big Poppa tests and the Tooele Army Depot Red Hat special tests. In the Big Poppa test 250,000 lbs. of HE were detonated en masse.

Slide #13 (Test Site Layout)

This artist's concept depicts the general layout of the test range. The barricaded instrument van was used to control each shot and record the data acquired from that shot. Instrumentation and control lines were run underground to 1, 4, 10 and 40 psi junction box stations shown on the slide. Pigtail cables were provided at each of the junction boxes of such length to permit rapid movement of blast pressure and ground shock measuring transducers to the optimum calculated location to record data for a specific shot. In many instances, the transducer locations selected served for a pair of shots, i.e. shots 1 & 2, 3 & 4, 5 & 6. It was imperative that virgin ground be used for each test location and that only undisturbed ground existed between the shot and all ground shock transducer locations. Documentation of test events was provided by real time and high speed movie cameras. One real time and one 1000 FPS camera~~s~~ ~~were~~ was located one mile beyond and looking down on this site from a hillside vantage point. A battery of barricaded cameras consisting of real time, 2000, 4000, and 8000 frames per second "Hi-Cam" cameras were located adjacent to the 4 psi junction box station. A real time and closed circuit TV camera were also mounted above the barricaded instrument van. The CCTV provided personnel in the instrument van with a means of constantly monitoring the test area.


T 205 TEST SITE LAYOUT SHOTS 1 10
10
6
5
1
2
3
4
8
9

Slide #14 (Trenches for Wiring)

All control wiring and instrument cables were buried between the barricaded control van and the test site to protect the 3500 feet of transmission lines from blast, schrapnel or damage by test personnel traffic.

Slide #15 (Junction Box and Air Blast Gage Stations)

One of the control and instrumentation junction boxes can be seen in the background. Two each Bytrex and two each self-recording BRL gages installed in pre-cast moveable concrete cubes can be seen in the foreground. Long pigtails were provided at each of the four junction boxes to permit movement of the air blast pressure measuring instruments mounted in their concrete cubes to the calculated distance from the test to record time of arrival, side-on blast overpressures experienced and their duration.

Slide 316 (Barricaded Instrument Van)

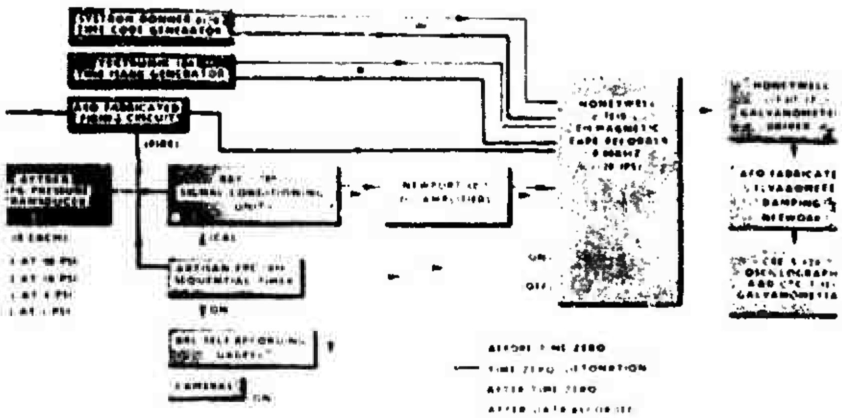
This earth covered steel arch structure provided shelter for our instrumentation vans. The real time documentary movie camera and closed circuit TV camera can be seen mounted on the roof.

Slide #17 (Instrumentation Schematic)

This instrumentation system proved to be extremely efficient in controlling test activities and recording results. The system was recommended by the Ballistics Research Laboratory. The nucleus of the system is the Artisen sequential timer. It was programmed to activete cameras in time to insure their operation at the desired frame per second filming speed at shot time, activate the BRL self-recording air blast gages, start the magnetic tape recorder and activate the firing circuit. The signal conditioning unit provided voltage excitation to eight Bytrex pressure trensducers. Millivolt signals produced by the Bytrex pressure transducers are amplified to volt range by the Newport amplifier before being recorded by the magnetic tape recorder. The time code generator provides a binary coded decimal output to the tape recorder for later positive correlation of recorded events with exact day of the year, hour, minute and second. The time mark generator provided 1000, 10,000 and 100,000 timing marks per second on the magnetic tape for later resolution of date. The equipment shown to the right of the tepe recorder is used to reproduce and amplify signals from the 14 channel magnetic tape to a readable chart printed by an oscillograph.

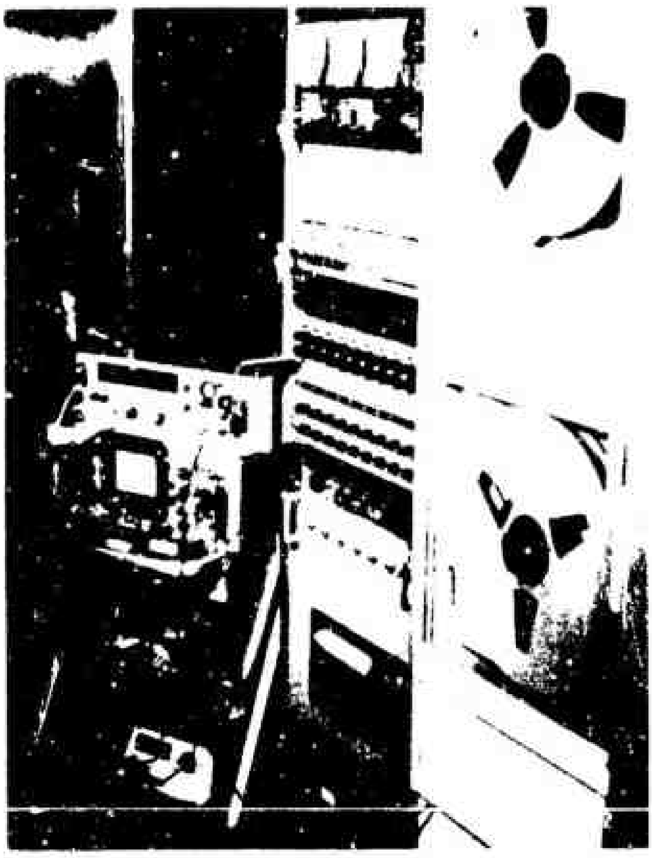
AIR BLAST PRESSURE AND CAMERA CENTRAL INSTRUMENTATION

RECORD AND REPRODUCE ELECTRONICS



Slide #18 (Mobile Instrumentation Van)

This is an interior shot of the Porta-Camp structure used for a mobile instrumentation van.

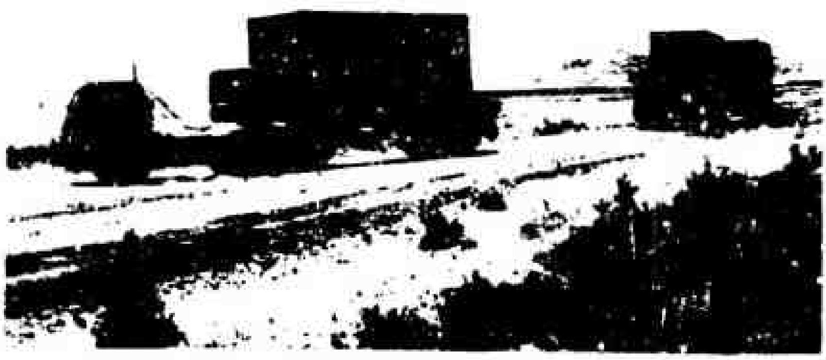


Slide #19 (Container Stuffing)

These Milvan containers were received and stuffed at Tooele Army Depot. Care was exercised to insure that stuffing was accomplished in exact accordance with drawings provided by the AMC Ammunition Center. New Milvans were used for buffer containers and unserviceable Milvans were used as donors and acceptors.

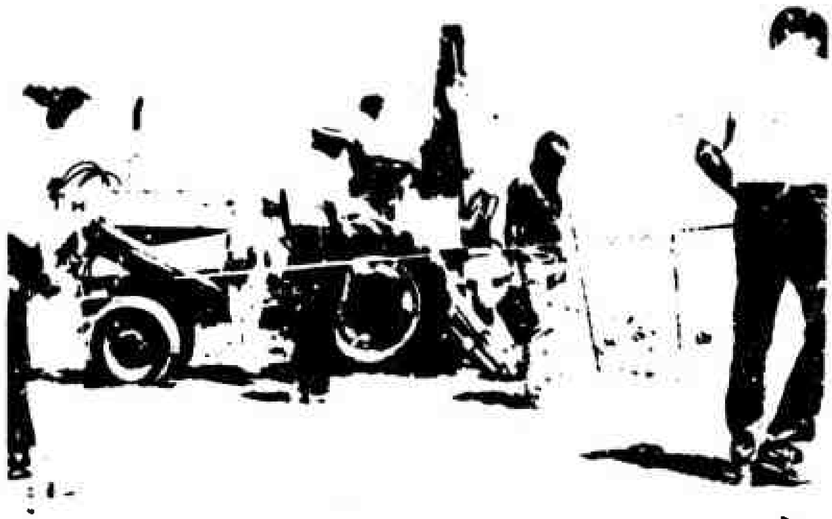
Slide #20 (Container Transport)

After stuffing at Tooele, the Milvans were transported approximately 75 miles to the Lakeside Test Range.



Slide #21 (Excavation for a Test)

Part of the criteria provided by the DODESB for the execution of the propagation test was that the confinement by a ships' hold surrounded by water be equalled or exceeded by placing donor buffer and acceptor containers into excavations that places the top of the Milvan 12 inches below the ground surface.

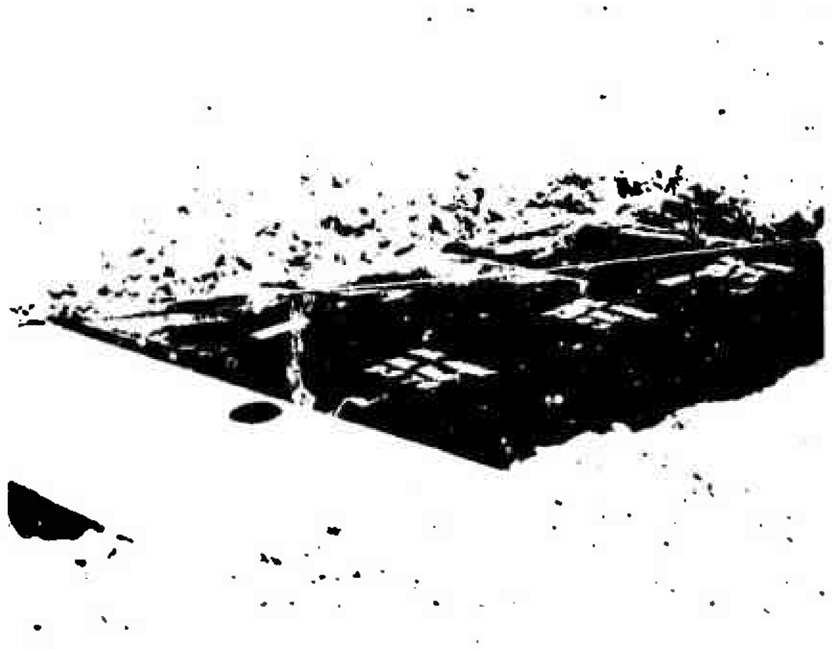


Slide #22 (Placing Milvan in Hole)

Extreme care was exercised in spacing Milvans in exact accordance with shipboard stowage configuration. After all containers were emplaced, the space between the exterior of the containers and the outside of the excavation was back filled and compacted. Extreme care was taken to prevent dirt from entering the spaces between the different containers.

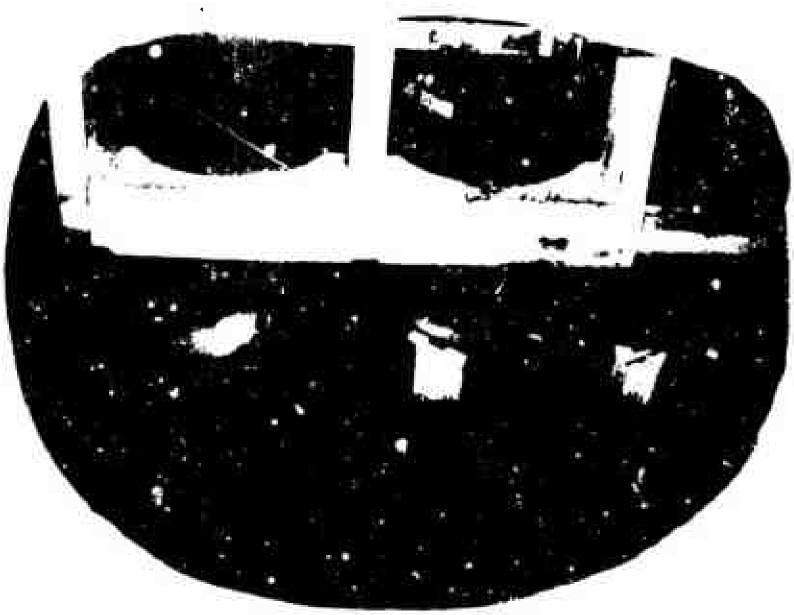
Slide #23 (Milvans Ready for Test)

This is a typical test arrangement. A donor Milvan with 72 each 500 lb. bombs is at the extreme left. Note the hole cut into the roof that will be used for ingress of the firing circuit. The two center Milvans each contain 600 90MM Comp B loaded cartridges. In this case the acceptor Milvan, on the extreme right, is also loaded with 72 each 500 lb. Tritonal filled bombs. Total high explosive involved in this test was 43,332 lbs.



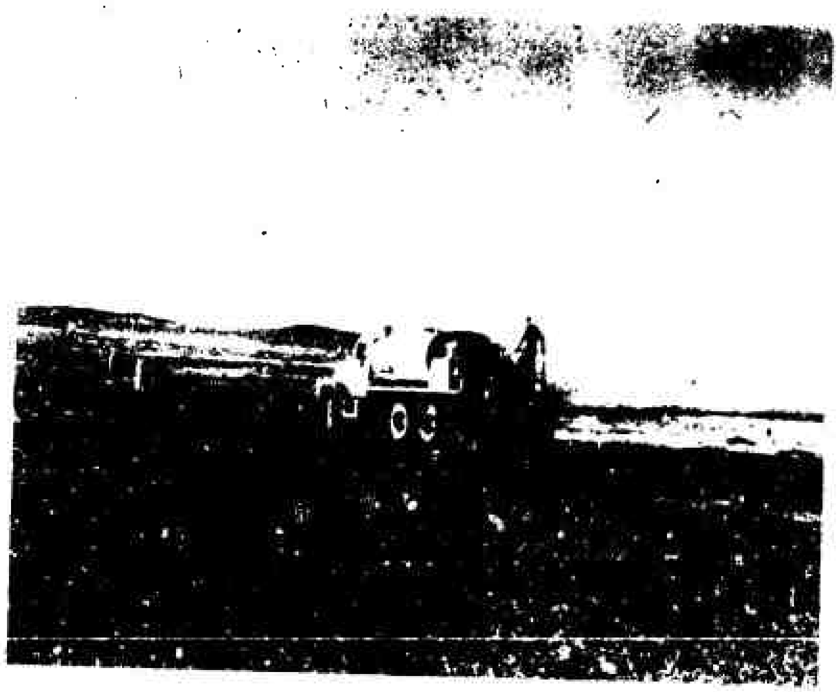
Slide #24 (Hole in Top of Milvan)

This hole permits access to bomb fuze cavities for placement of electrically initiated burster charges in two of the bombs in the donor container.



Slide #25 (Water Truck)

Just prior to shot time several truck loads of water were used to thoroughly wet down the area surrounding the test site. This action greatly reduced the dust resulting from the detonation and thus permitted much better quality test movies for analysis of results.



Slide #26 (Detonation)

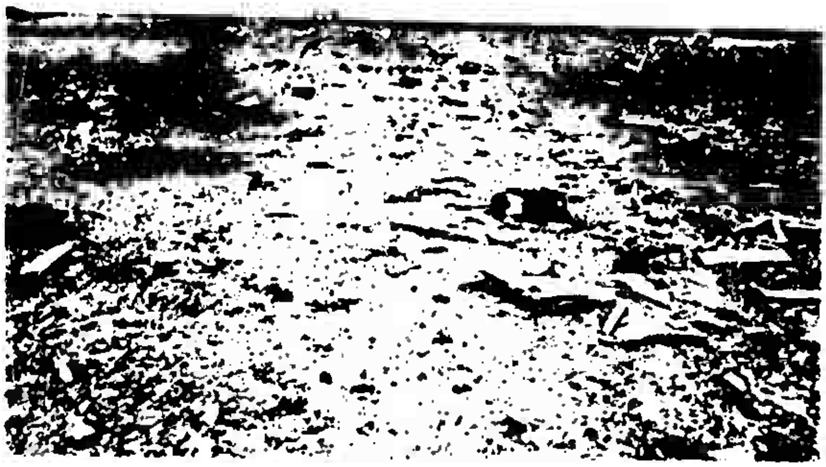
This slide depicts a test detonation. In this particular case only the donor and a small amount of the buffer munitions were consumed in the detonation.

Slide #27 (Measuring the Crater)

The analysis of test results was conducted on the day after the test detonation. One of the most meaningful measures of the total contribution by the percent of the explosives initiated or propagated in any test was the accurate measurement of the crater produced as depicted by this slide.

Slide #28 (Debris from Test)

The next step in analysis cf test results was the search and plotting of buffer and acceptor Milvan contents expelled from the test site.

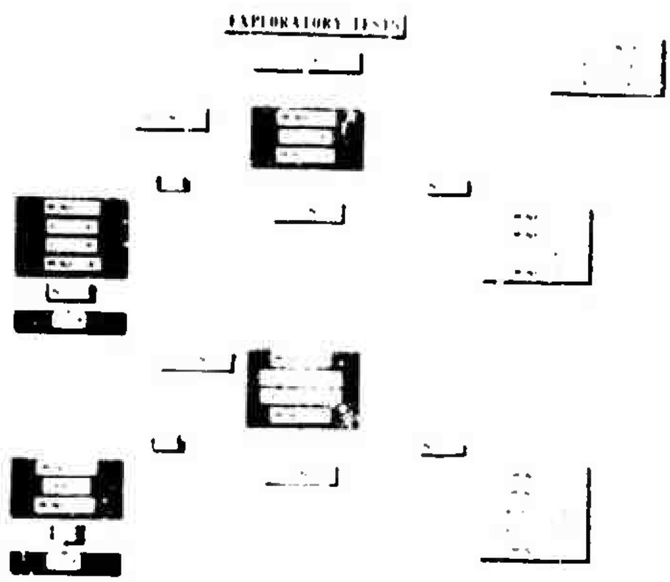


Slide #29 (Unexploded Ordnance)

The final step in the completion of field test efforts was to clean up unexploded ordnance items and destroy them by EOD procedures.

Slide #30 (Exploratory Tests)

The container propagation tests have been pursued in [illegible]e separate phases. In a series of eight prefatory tests (not shown on this slide) the comparability of Comp B loaded 90MM and 105MM ammo was established. The need to eliminate pallet slots through Milvans stuffed with boxed ammo and a rough idea of the mass density required to stop propagation was determined. Exploratory Tests #1 through #4, shown on this slide, provided a test bed for the evaluation of various candidate buffer material stuffed containers. Test #2 proved the value of two 90MM stuffed Milvans used to separate mass detonation type explosive stuffed Milvans. Propellant charge stuffed containers used as buffers in Test #3 reacted like mass detonating type material to contribute significantly to the measured air blast pressures. In Test #4 one small arms ammo stuffed Milvan proved to be inadequate to stop propagation. Follwing is a resume of exploratory test results:



EXPLORATORY TESTS

TEST #1	D - 384	Mines	Expl Wt	8,724 Lb.
	B - 600	90MM Cart.	Expl Wt	1,290 Lb.
	A - 384	Mines	Expl Wt	8,724 Lb.
		TOTAL WT		18,738 Lb.

Results - High order propagation

Recovered - 36 each 90MM Proj

Crater - 102' x 96' by 20'

TEST #2	D - 384	Mines	Expl Wt	8,724 Lb.
	B - 600	90MM Cart	Expl Wt	1,290 Lb.
	B - 600	90MM Cart.	Expl Wt	1,290 Lb.
	A - 384	Mines	Expl Wt	8,724 Lb
		TOTAL WT		20,028 Lb.

Results - High order detonation followed by fires. 2d detonation believed to be acceptor seven minutes after first detonation.

Recovered - 241 Mines

322 Proj

1 Cart Case

Crater - 85' x 101' by 19' 6"

TEST #3	D - 384	Mines	Expl Wt	8,724 Lb.
	B - 540	155MM Prop Ch	Expl Wt	16,740 Lb.
	B - 540	155MM Prop Chg	Expl Wt	16,740 Lb.
	A - 384	Mines	Expl Wt	8,724 Lb.
			TOTAL WT	50,928 Lb.

Results - High order propagation

Recovered - None

Crater - 126' dia by 25' 6" deep

TEST #4	D - 384	Mines	Expl Wt	8,724 Lb.
	B - 100,800	.50 Cal Cart	Expl Wt	10,195 Lb.
	A - 384	Mines	Expl Wt	8,724 Lb.
			TOTAL WT	27,643 Lb.

Results - High order propagation

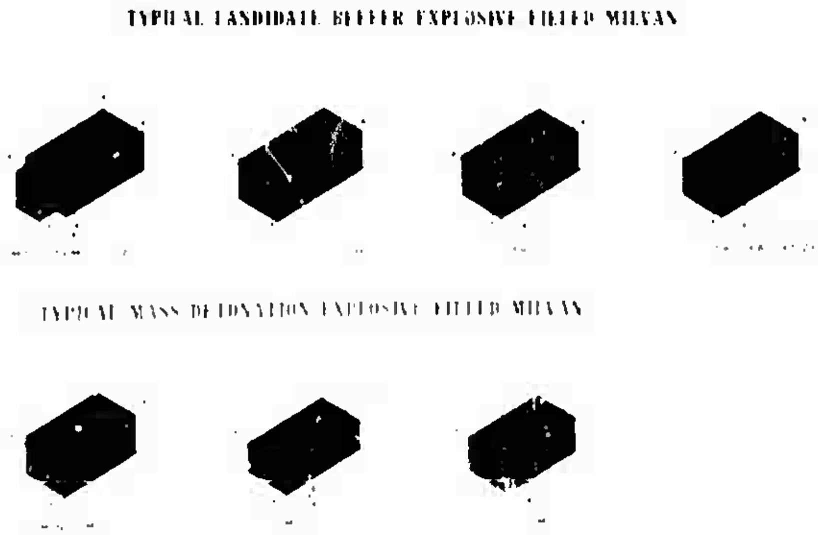
Recovered - 246 Mines

Many .50 Cal Cart.

Crater - 91" dia by 13' 6" deep

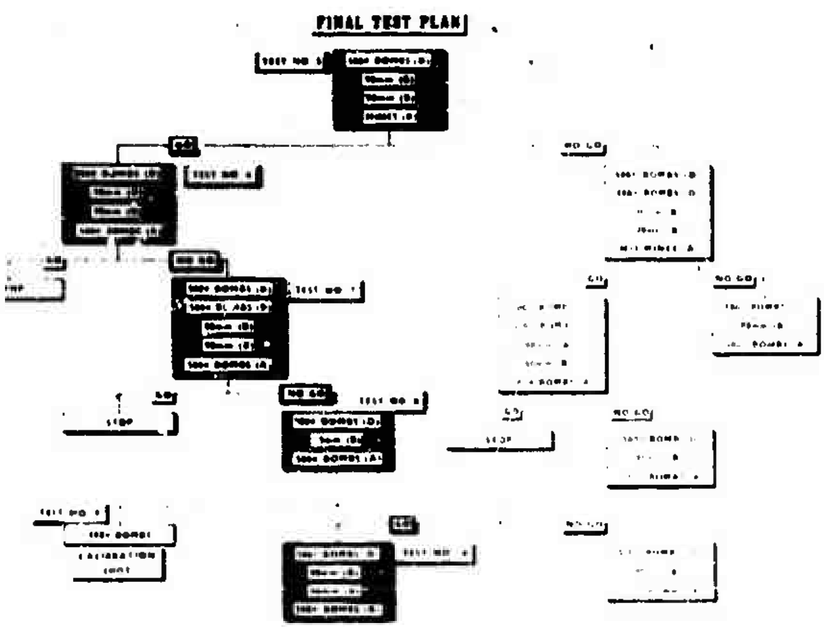
Slide #31 (Container Content Configurations)

This slide depicts considerations to be observed in selecting buffers to separate cells of mass detonating munition stuffed Milvans. Small arms ammo, due to its weight, cannot be stuffed to occupy the available volume of the Milvan. The reduced mass density presented by the single pallet thickness of small arms at the one end of the buffer Milvan most likely permitted the propagation experienced in Exploratory Test #4. Utilization of a double buffer should eliminate any future failures.



Slide #32

In this series of tests, the suitability of two Class 5 munition stuffed buffer Milvans to stop propagation or communication between mass detonating heavy cased munition stuffed Milvans was established. In test #10, palletized 90MM cartridges with pallet slot fillers were stuffed in the buffer containers. Following is a resume of this test series:



FINAL TESTS

TEST #5	D - 72	Bombs 500#	Expl Wt	20,376 Lb.
	B - 600	90MM Cart.	Expl Wt	1,290 Lb.
	B - 600	90MM Cart.	Expl Wt	1,290 Lb.
	A - 384	Mines	Expl Wt	20,376 Lb.
		TOTAL WT		43,332 Lb.

Results - High order detonation

Recovered - 36 each 90MM Proj

Crater - 124' dia by 19' deep

TEST #6	D - 72	Bombs 500#	Expl Wt	20,376 Lb.
	B - 600	90MM Cart	Expl Wt	1,290 Lb.
	B - 600	90MM Cart.	Expl Wt	1,290 Lb.
	A - 72	bombs 500#	Expl Wt	20,376 Lb.
			TOTAL WT	43,332 Lb.

Results - Donor and one buffer high order detonation

Second buffer and acceptor low order detonation

Recovered - 292 90MM Proj

72 Bombs

Crater - 66' dia by 25' 5" deep

TEST #7	D - 72	Bombs 500#	Expl Wt	20,376 Lb.
	D - 72	Bombs 500#	Expl Wt	20,376 Lb.
	B - 600	90MM Cart	Expl Wt	1,290 Lb.
	B - 600	90MM Cart.	Expl Wt	1,290 Lb.
	A - 72	Bombs 500#	Expl Wt	20,376 Lb.
			TOTAL WT	64,008 Lb.

Results - Some bombs in donor did not detonate

Recovered - 505 90MM Proj

82 500# Bombs

Crater - 111' dia by 25' deep

TEST #8	D - 72	500# Bombs	Expl Wt	20,376 Lb.
	B - 600	90MM Cart	Expl Wt	1,290 Lb.
	A - 72	500# Bombs	Expl Wt	20,376 Lb.
			TOTAL WT	42,042 Lb.

Results - High order propagation

Recovered - 75 90MM Proj

22 500# Bombs

Crater - 104' dia by 25' 3" deep

TEST #9 D 72 500# Bombs Expl Wt 20,376 Lb.

Results - High order detonation (3 ea bombs low order)

Crater - 95' dia by 14' deep

TEST #10	D-72 500# bombs	Expl Wt	20,376 Lb.	
	B-480 90MM Cart.	Expl Wt	1,032 Lb.	Palletized
	B-480 90MM Cart.	Expl Wt	1,032 Lb.	
	A-72 500# Bomb	Expl Wt	20,376 Lb.	
		TOTAL WT	43,332 Lb.	

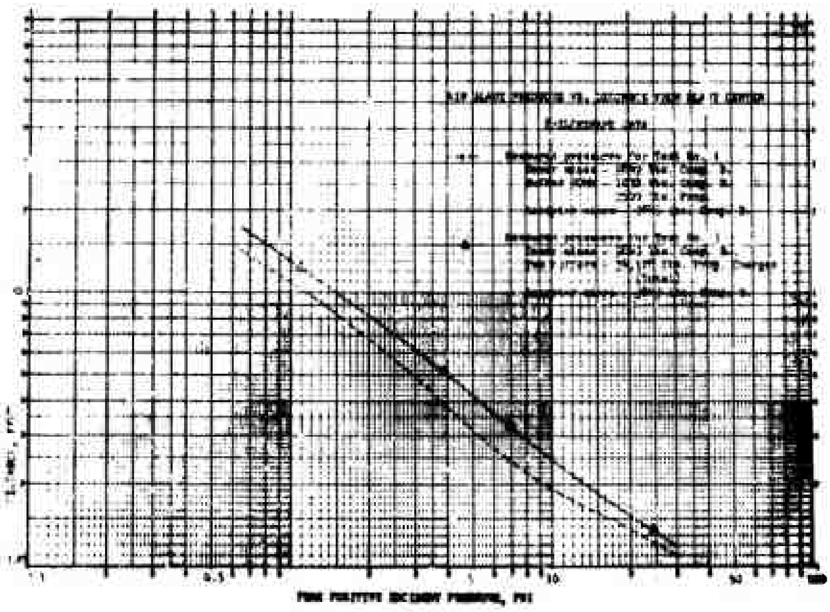
Recovered - 257 90MM Proj

67 500# Bombs

Crater - 102' dia by 19' 6" deep

Slide #33 (Air Blast Pressures)

This graph compares the air blast pressures resulting from Exploratory Test #1 and #3. In Test #1, 768 each mines were detonated and in Test #3, 768 each mines were detonated. The significant difference between the blast pressures witnessed was therefore the contribution by 1080 each M19, 155MM propellant charges. These charges are currently listed as Class 2, single base, multi-perforated propellant.



Slide #34 (Detonation Residue)

Over 7000 each 90MM M71 cartridges were stuffed into Milvans used as buffers. This slide shows the only cartridge case, even partially intact, that was recovered.

Slide #35 (Air Blast Pressure Comparison)

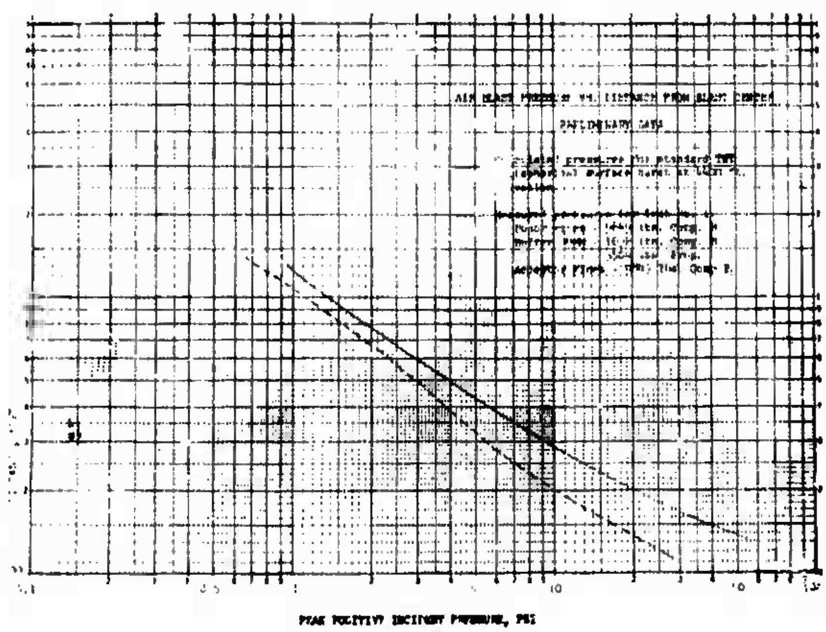
This graph compares air blast pressures established for hemispherical TNT charges detonated on the ground (corrected for Tritonal and 4400 ft. elevation) and blast pressure readings recorded after the detonation of the same size charge that was positioned below ground level. A similar deviation was consistent throughout the test. Note also that the percent of deviation is greatest at the closest distance to the detonation and that the degree of variation diminished as the distance from the detonation increases. This result may suggest some considerable advantage of underground storage or processing facilities over above ground facilities.

Reference:

Technical Report 3808

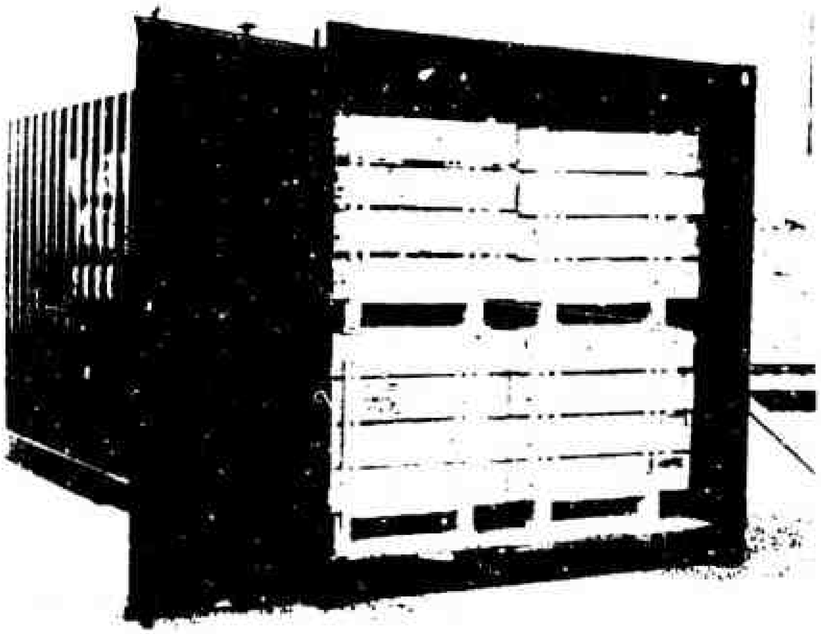
Manual for Design of Protective Structures Used in Explosive Processing and Storage Facilities

Figure 4-5 Shock Wave Parameters for Spherical TNT Explosion in Free Air at Sea Level


AIR BLAST PRESSURE VS. DISTANCE FROM BLAST CENTER
PRELIMINARY DATA
10
PEAK POSITIVE INCIDENT PRESSURE, PSI

Slide #36 (Pallet configuration)

During the prefatory test series, it was theorized that the pallet slots permitted fragment passage from the donor to cause propagation of the acceptor.

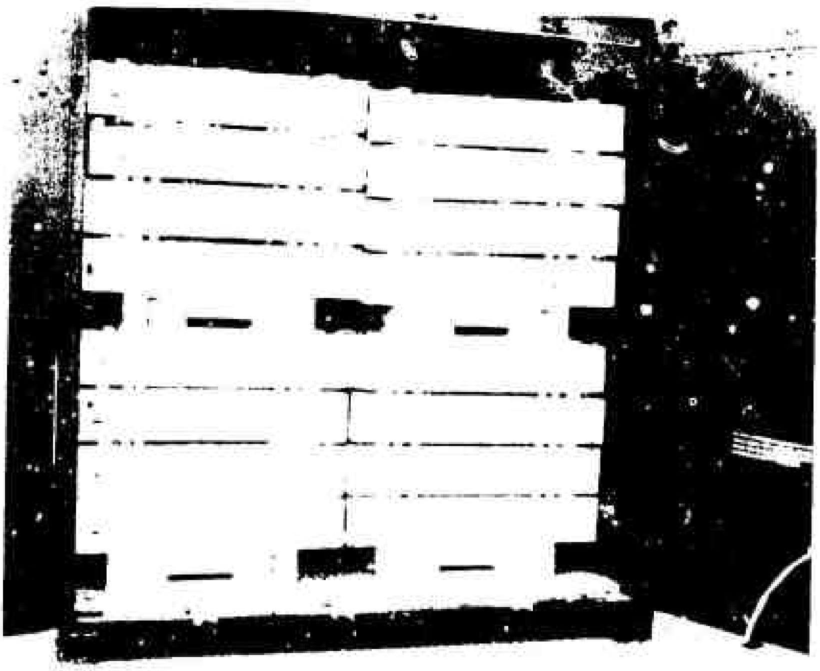


Slide #37 (Pallet Slot Filler)

The addition of this simple pallet slot filler increased the mass density adequately to defeat fragments.

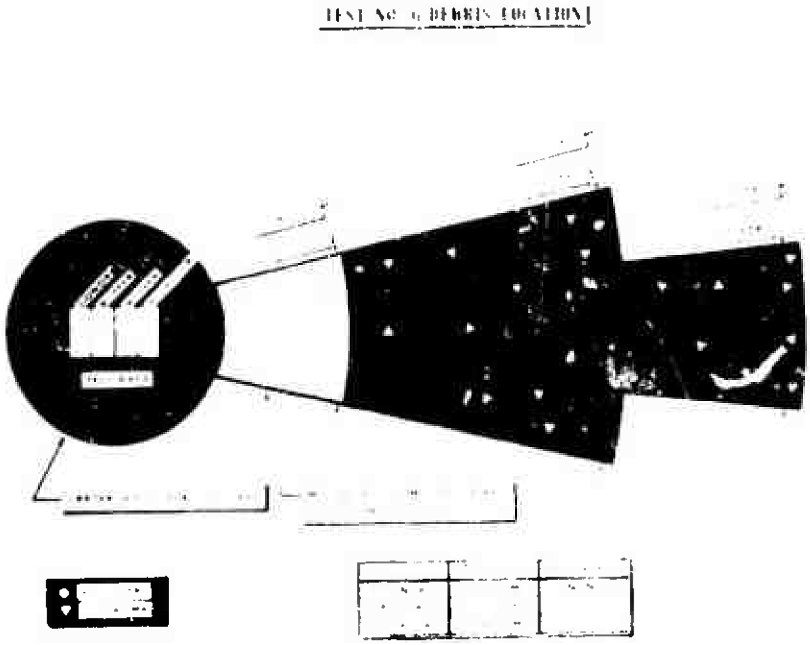
Slide #38 (Milvan/Munitions Configuration)

This slide depicts one of the two Milvan Buffers stuffed with palletized 90MM cartridges and pallet slot fillers as successfully tested in final Test #10.



Slide #39 (Test Debirs)

This slide depicts the extreme range over which debris, including unexploded munitions, was scattered. Note that several 500 lb. bombs were thrown in excess of 3000 feet.

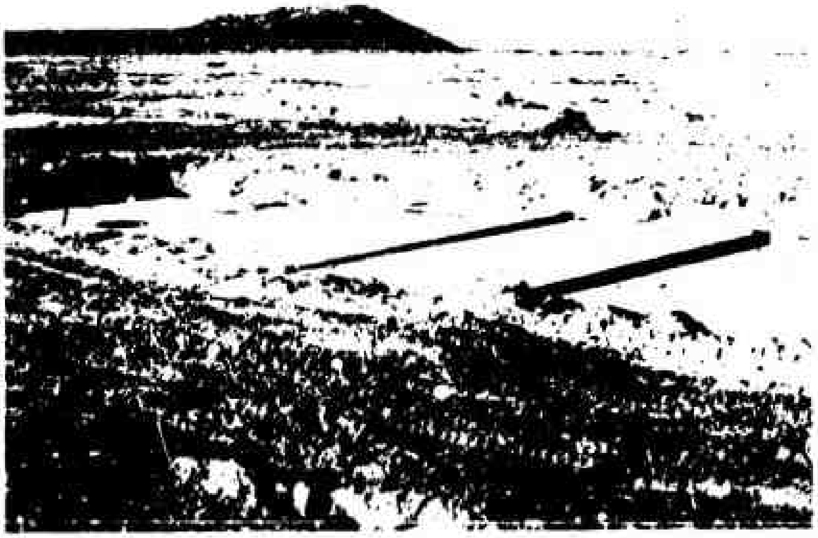


Slide #40 (Debris Distance)

This bomb was ejected from its position in the acceptor Milvan of Test #6 and thrown a distance of 3300 feet.

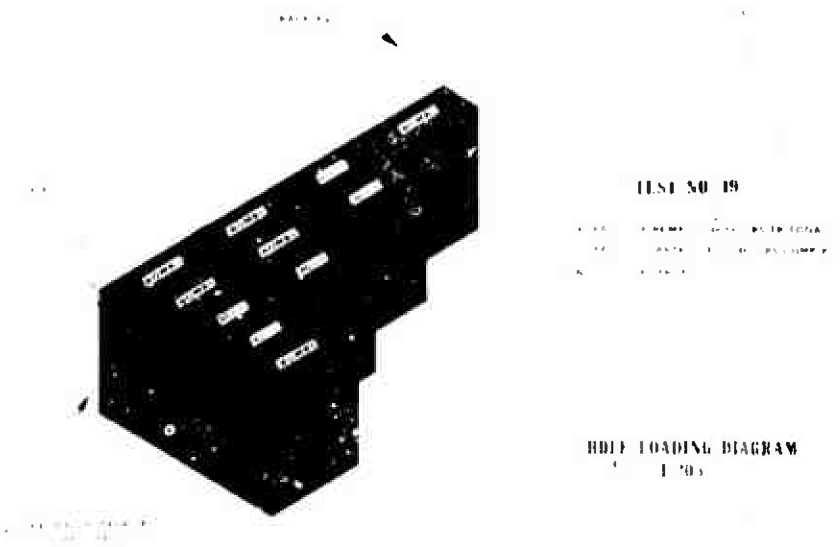
Slide #41 (Assumptions)

One of the major accomplishments of the study to date is the finding that two each Milvans stuffed with palletized Class 5 munitions, and having the pallet slots filled, impedes propagation or communication between Class 7 stuffed donors and acceptors.



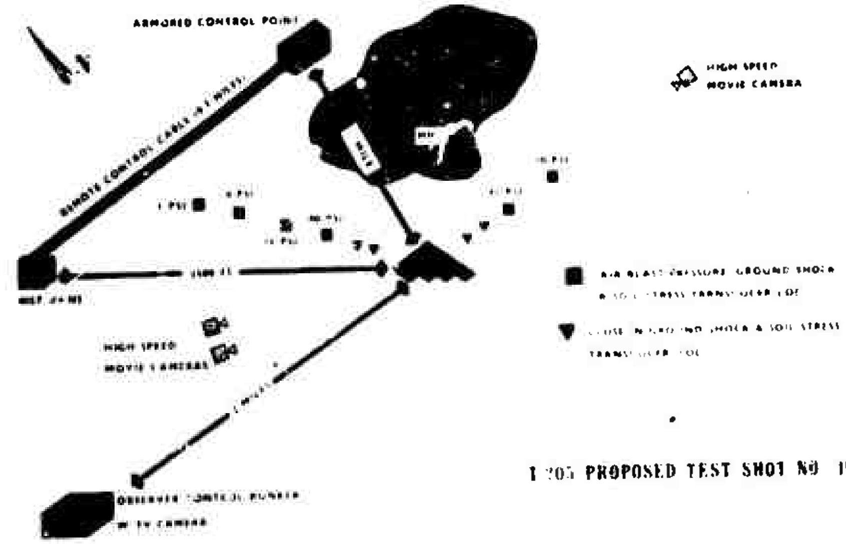
Slide #42 (Projected Test)

This slide depicts Test #19 currently planned for accomplishment in mid-January. This test will permit evaluation of the applicability of previous test results to the computation of quantity distances to be observed from container ships. Note that nearly 317,000 lbs. of energetic material will be amassed for this test.



Slide #43 (Site Configuration)

This slide shows the proposed range configuration for Test Shot No. 19. Thirty-three Milvans are stacked 3 high with the top of the stack flush with the ground. The Milvans are filled with 500 lb. bombs and 90MM proj. and arranged as shown on the previous slide. Two blast lines to measure air blast pressure, ground shock, and soil stress will be used; one line composed of transducers at the 1, 4, 10 and 40 psi levels and the other line composed of transducers at the 10 and 40 psi levels. It is anticipated that due to possible differences in propagation between Milvans positioned end to end and Milvans positioned side by side, it is likely that close in air blast pressures and ground shocks will be different along the various sides of the Milvan stack. The unmanned instrumentation vans will be located under a protective hanger and will be started and controlled from a manned barricaded bunker located behind a hill approximately 3/4 mile up range from the Milvan stack. Observers will be located in a barricaded bunker approximately 2 miles down range from the Milvan stack. Observation will be via closed circuit TV. High speed movie cameras will record the blast from two sides. The blast will be initiated in the North-East corner of the Milvan stack by detonating two bombs located in the middle Milvan in the vertical column of three.



T-205 PROPOSED TEST SHOT NO. 1?

INTERIOR BLAST PRESSURES OF ACCEPTOR MAGAZINES: ESKIMO I*

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Mason & Hanger - Silas Mason Co., Inc.
Pantex AEC Plant, Amarillo, Texas

ABSTRACT

This report describes the measurement of dynamic pressure-time histories within earth-covered, steel-arch acceptor magazines which were subjected to overpressures produced by the detonation of a central donor magazine containing 200,000 pounds of TNT cast in M101 155 mm projectiles.

Shockwave arrival times were monitored at the headwalls of four inward-facing acceptors located at scaled distances of 1.25 $W^{1/3}$ (Head to Side), 2.00 $W^{1/3}$ (Head to Head with intermediate barricade,) 2.00 $W^{1/3}$ (Head to Rear), and 2.75 $W^{1/3}$ (Head to Side). Equivalent explosive weight values are derived as functions of time and direction for near-field conditions, based on exterior arrival time data as well as negative phase amplitudes of experimentally observed pressure profiles inside the acceptor "igloos."

Since the test arrangement represented worst-case orientation for internal damage to adjacent magazines, some obvious safety aspects concerning potential personnel and equipment hazards are discussed with suggested improvements.

INTRODUCTION

The Department of Defense Explosives Safety Board is engaged in a program to more accurately determine the minimum safe separation distance between magazines storing explosives. This distance is the least which will provide assurance that an explosion in one magazine will not propagate to another although the second magazine and possibly its contents might be extensively damaged. Of particular interest to the AEC was the determination of air shock levels within the adjacent magazines to assess probable personnel effects and equipment damage. Previous tests(*1*) have demonstrated that earth-covered steel-arch igloo magazines can be safely spaced side to side at a distance in feet determined by 1.25 $W^{1/3}$ in which W is the weight in pounds of the high explosive in storage. However, little information has been developed which will indicate the minimum safe distance between the concrete headwall of the magazine and the earth covered side, rear or barricaded headwall of another magazine. To determine the minimum safe separation distances when the headwall faces the donor explosion the Department of Defense Explosives Safety Board sponsored the Eskimo I Test.

***** *Work performed under auspices of the U. S. Atomic Energy Commission in cooperation with the Department of Defense Explosives Safety Board, sponsors of the Eskimo I test conducted at Naval Weapons Center, China Lake, California on December 8, 1971.*

DISCUSSION

TEST ARRANGEMENT

The general plan of the test(2) consisted of locating four standard height and width igloo magazines about a donor magazine which contained 200,000 pounds of high explosives. The four acceptor igloo magazines faced the donor and were located at various distances determined by factors ranging from 1.25 $W^{1/3}$ to 2.75 $W^{1/3}$. The nearest acceptor igloo was spaced 73 feet east of the steel arch of the donor magazine at a scaling factor of 1.25 $W^{1/3}$. The south acceptor igloo was spaced 117 feet from the rear wall of the donor igloo and the north acceptor igloo was spaced 117 feet from the headwall of the donor igloo with a scaling factor of 2.0 $W^{1/3}$. The west igloo was spaced 161 feet from the steel arch of the donor magazine with a scaling factor of 2.75 $W^{1/3}$. Two 20-foot wide x 25 foot long storage structures were built near the corners of the earth cover over the north acceptor igloo with their solid front wall located 117 feet from the nearest corner of the donor magazine. The structures were built of cement block and did not include a floor. A 15 1/2-foot high earth barricade (uncompacted) was installed between the donor and the north acceptor magazines with the toes of its side slopes 25 feet from the acceptor and 27 feet from the donor. A plan view of the test arrangement complete with AEC instrument locations is shown in Fig. 1. Pretest photographs are shown in Fig. 2.

Cased acceptor charges were located in each of the acceptor igloos to provide evidence of the explosion propagating to the acceptor magazines. Each igloo contained eight of these spherical cyclotol charges (four each of two types) arranged alternately in two rows of four across the face of the magazine, approximately 2 feet behind the headwall and doors on wooden stands. Centerline height of the bottom row was about 2 feet off the floor, and the other row, above it, was about 5 feet off the floor. Both types of acceptor charges contained, principally, cyclotol; Type I contained 103 pounds without detonators and Type II contained 180 pounds including a full complement of detonators.

Six acceptor charges (three of each type) were located similarly in the NE concrete block magazine, while the NW blockhouse contained two missile propulsion sections as acceptor charges.

The donor charge for the experiment consisted of 200,000 pounds of TNT contained in 13,704 155 mm M101 projectiles. These were stacked in place using 1,713 pallets with eight projectiles per pallet and physically filled the igloo except for a small vacancy left near the doors for forklift access. The ammunition stack was initiated by simultaneously igniting equal lengths of primacord connected to individually fused projectiles located at each of the eight corners of the stack and in each of the five layers in a vertical column at the center of the stack.

INSTRUMENTATION

The pressure transducers used for the test were Kulite type XTS-190(3). These are miniature strain gage type transducers containing a silicon diaphragm on which a Wheatstone bridge has been diffusion bonded. Each transducer had a

small reference tube emerging from its back side which was sealed at an atmospheric pressure of 936 millibars such that each transducer read differential pressure.

An array of 3 transducers was located centrally in each of the four acceptor igloos. These were positioned on a stand 2 feet above the floor and were directed to read head-on, side-on, and rear-on pressures within a 1-1/2 inch radius of each other. Each of the head-on gages in the acceptor igloos were fitted with Kulite type M shields, which are small perforated screens used to resist particle impingement in severe environments.

Each pressure transducer station was fitted for calibrations using pressurized dry nitrogen. A typical gage array showing both the calibrate mode and test mode is shown in Fig. 3.

Individual transducers were mounted near ground level, centrally inside each cement blockhouse and 2 feet outside the forward wall of each blockhouse. These were for side-on pressure measurement only.

Five shock motion detectors (pressure-activated switches) were installed for measuring arrival times. One was mounted on each acceptor igloo headwall and one was positioned on the top center of the donor igloo to obtain a zero time reference point. Locations of blockhouse transducers and shock motion detectors are shown in Fig. 4.

The record/reproduce instrumentation system was located in an instrument barricade approximately 1,000 feet west of the donor igloo. The signal monitoring system included differential amplifiers driving a magnetic tape recorder and an oscillograph. The transducers were connected through long underground control cables which entered a 2" conduit at the rear of each acceptor igloo and emerged in the floor at the center of the igloo. A simplified block diagram of the record/reproduce instrumentation system is shown in Fig. 5.

The calibration procedure consisted of pressurizing each gage incrementally at its location; i.e., through the long control cables, the longest of which was 1475 feet, and monitoring the output voltage at the instrument barricade. Each input channel was then calibrated by inserting known voltage steps to ascertain the deflection sensitivity of each channel. Three complete calibration runs were made on all of the gages, the final run being made just prior to the test. Since the instrument barricade was not manned during the test, the equipment functions were remotely programmed from a control center located approximately 8 miles away.

PRESSURE MEASUREMENTS

Of the 16 transducers installed, two were scratched prior to the test; one had an open bridge circuit and the other a ruptured diaphragm. One of these was located outside the northwest blockhouse and the other was located inside the north acceptor igloo, rear-on. The remaining exterior pressure gage was located at a scaling factor of 2.0 $W^{1/3}$ to achieve correlation with NWC pressure data.

Due to the test configuration and manner of donor detonation the emerging shockwaves were directional, thereby complicating data correlation (measurement of a zero time reference was valid only in the direction measured). Actually, the test was designed to produce heavy fragmentation (more than 1 million pounds of steel was fragmented by the donor) for comparison with previous tests using bulk explosives and did not lend itself well to prediction of expected overpressures.

Calculations made for a single M101 round in the donor stack, based on an approximative model using a casing weight to charge weight ratio of 5 to 1, yielded blast wave production efficiences as low as 50 percant ($W^{1/3} = 46$). However, pressure enhancement due to reflections and interactions from adjacent rounds would tend to increase this efficiency number. Moreover, pressure estimations were further complicated by the initiation geometry of the donor, directional effects due to donor configuration, charge weight to structure volume ratio and response or failure time of the doors and headwalls of the acceptor magazines. Therefore, selection of pressure ranges for transducers was weighed to worst-case conditions.

One external pressure measurement was obtained near the NE blockhouse and interior pressures were monitored for each acceptor igloo and the NW blockhouse. Selected pressure-time profiles are shown in Fig. 6 and the reduced data is given in Table I.

TEST RESULTS

Preliminary NWC data(4) indicate that the donor blast was equivalent to a cubicle-confined detonation(5) of 100,000 pounds of TNT ($W^{1/3} = 46.5$) from far-field, BRL pressure gage measurements. Directionally, the effective $W^{1/3}$ values were 51,47 and 41 for front, side, and rear of the donor, respectively. NWC near-field pressure data, measured in the acceptor igloo complex, show reduced effective $W^{1/3}$ values ranging from approximately 24 to 32.

AEC data also exhibits near-field anomalies, at least for the positive phase portion of the blast. Effective $W^{1/3}$ values computed from near-field negative phase amplitudes were in closer agreement with far-field measurements. Presumably, the mechanisms affecting positive phase characteristics were no longer contributing factors during negative phase, i.e., breeching of the donor magazine, rupture of acceptor doors, etc.

A mach stem with a triple point height several feet above ground level was observed in the high-speed camera views of the shockwave approaching the south acceptor igloo. This suggested that near-field positive phase effects were more associated with that of an air burst rather than a surface burst, therefore, effective $W^{1/3}$ values were computed for both air and surface bursts for comparison. Apparently, a combination of the characteristics of both types of bursts affected near-field measurements, depending on direction from the donor. Effective $W^{1/3}$ calculations from arrival time and negative phase date, corrected to sea level, are given in Table II.

These data are plotted in Fig. 7 with scaled curves taken from Fig. 4-12 of Reference 5.

The calculations based on arrival times are subject to inherent directional errors of as much as 5 msecs. Attempts to correct the measured arrival time for each direction, using NWC high-speed camera views of the donor breeching sequence, yielded effective cube-root weights which were still substantially lower than far-field results.

The high-speed camera records showed that first light emerged from the doors of the donor igloo about 5 msecs prior to ground shock activity near the zero time motion detector atop the earthen fill of the donor. The reference time is thus off-set from the first eruption of the detonation, but is assumed to be representative of the finite time required from detonation of the first rounds to essentially complete detonation of the entire stack. According to high-speed camera data, approximately 9 msecs elapsed from the first light eruption at the front of the donor to the last of a sequence of gas ventings which progressed along the top of the earthen fill toward the rear of the donor.

The time off-set discussed above is not critical for evaluation of far-field measurements but is of importance for interpretation and correlation of near-field results, i.e., those measurements taken near the acceptor igloos. For example, all effective cube-root explosive weights estimated from near-field positive phase measurements (listed in Table I) are smaller than the average value of 46.5 estimated from far-field results. Effective weights, estimated from time of arrival data, were obtained by selecting values of effective cube-root weight such that calculated points for scaled arrival time and distance agree with the idealized, scaled time of arrival curve of Fig. 7. Effective explosive weights were also estimated from results of the external transducer located at the base of the northeast concrete magazine. The recorded side-on pressure (85.4 psi) corresponds to an effective cube-root weight of 41 and the arrival time to 35 $W^{1/3}$ for a surface burst; 46 $W^{1/3}$ and 41 $W^{1/3}$ respectively, for an air burst.

Effective weight calculations based on near-field measurements, are not intended to conclusively determine donor charge. They do however, indicate that blast conditions experienced by the igloos were not as intense as might be expected from far-field measurements.

POST-TEST EXAMINATION

The blast wave from the donor was apparently focused toward the north, through the doors and headwall in a typical gun effect. All acceptor units detonated in the east igloo (1.5 $W^{1/3}$ effective). The damaged rear wall and wing walls were all that remained standing near original positions. The steel arch had been blown approximately 50 feet to the northeast and was distorted and riddled with secondary shrapnel holes. The north, south, and west acceptor igloos sustained heavy damage on headwalls and doors with the damage generally localized near the doors. The two concrete block magazines were reduced to rubble. Photographs of the damage are shown in Figs. 8 and 9.

Four acceptor units burned in the north igloo (2.5 $W^{1/3}$ effective) and both missile propulsion sections burned in the northwest blockhouse. The acceptor units were buried in the debris of the northeast blockhouse.

Notably, the least blast-resistant structures were the concrete block magazines and the blast doors were the weakest structural elements of the igloo magazines.

OPERATIONAL SAFETY ASPECTS

Predictions of biological effects(6) and equipment damage are strongly dependent on the test configuration. Due to early blast door failures and resulting line of sight propagation of donor fragmentation, fireball, blast wave, and debris, Eskimo I represents a worst-case condition for potential damage to acceptor igloo interiors. For example, increasing the pressure-resistance of blast doors and observing side-on orientations between igloos, coupled with the additional protection provided by the earthen fill, would probably negate fragmentation damage and reduce fireball produced effects within adjacent igloos.

Since the instrumentation described here only provides interior pressure-time information, the discussion of probable interior effects will, henceforth, be restricted to blast produced damage and obvious conclusions derived from post-test examination. Further, for purposes of discussion, the pressure transducers used to instrument the igloos will be defined as "delicate instruments."

Tentative criteria for biological effects are given in Ref. 6, where effects of blast and shock are subdivided into three categories termed primary, secondary, and tertiary. Primary effects, those directly due to applied pressure encompass both positive and negative phases. However, effects resulting from the negative phase have not been established. Criteria for biological damage in Ref. 6 are based on "fast-rising" long-duration pressure-time histories. Except for the east igloo, the overpressures observed were classed as "slow-rising", effecting a decrease in potential biological damage for a given peak overpressure. For example, even though the probability of personnel injury from overpressures was below threshold for the west and south igloos, survival would still have been unlikely due to debris.

Only four undamaged transducers were recovered. These transducers were mounted side-on and rear-on in the south igloo, rear-on in the west igloo, and side-on in front of the northeast concrete magazine. All other transducers were either destroyed or rendered partially inoperable. The probability of extensive equipment damage was thus at least 50 percent in the south and west igloos and close to 100 percent within the remaining structures.

CONCLUSIONS

Realistically, any quantity-distance values derived from Eskimo I, for use in establishing minimum safe separation distances for planning storage sites, should be scaled to an effective explosive weight of 100,000 pounds ($W^{1/3}$ = 46.5). Using this value, a significant decrease in the spacing between the rear of one igloo and the front of another is justified—from a scaled distance of 4.5 (ft/$W^{1/3}$), previously tested, to at least 2.5 (ft/$W^{1/3}$).

Anomalies in near-field measurements are not fully understood, but appear to be caused by complex shockwave diffractions from the donor configuration. The apparent close agreement between effective cube-root weights computed from near-field negative phase amplitudes and far-field positive overpressure measurements indicates that the negative phase was less dependent on initial geometry.

Orientation of magazines within a storage complex is equally as important as their spacing. From the standpoint of operating personnel safety, adjacent igloos within a complex should be ideally arranged such that no line-of-sight path exists between any igloo and the doors of another. Reinforcement of magazine blast doors would enhance safing of stored explosives and equipment in closed magazines, but this would afford little more protection for operating personnel under present operating conditions: Typically, the doors of an occupied igloo are left open due to inadequate light and/or ventilation or to transfer materiel in or out. Therefore, lethal overpressures might be experienced within an occupied igloo, regardless of orientation, under current quantity-distance guidelines. Nevertheless, closed doors with people inside similar operational (not storage) structures is a possibility; and a variety of items whose protection is important are stored in closed-door igloos.

The second and third order effects of acceleration and flying debris were dominant features of the Eskimo I test arrangement and rendered the south and west acceptor igloos—with closed doors—unsafe for potential occupants or materiel, although they could be deemed marginally "safe", considering overpressure levels alone.

ACKNOWLEDGMENTS

The authors gratefully acknowledge R. B. Linville and J. H. McMenamin for their valuable assistance in test instrumentation, still photography, and reproduction of the test data.

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3. Technical Bulletin, KPS-XT-190 D Kulite Semiconductor Producte, Inc., Ridgafiald, New Jersey.

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5. TM 5-1300, Structures to Reaist the Effects of Accidantal Explosione, Juna 1969.

6. Biological Effects of Blast and Shock, April 1966, Donald R. Richmond, et al, Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico.

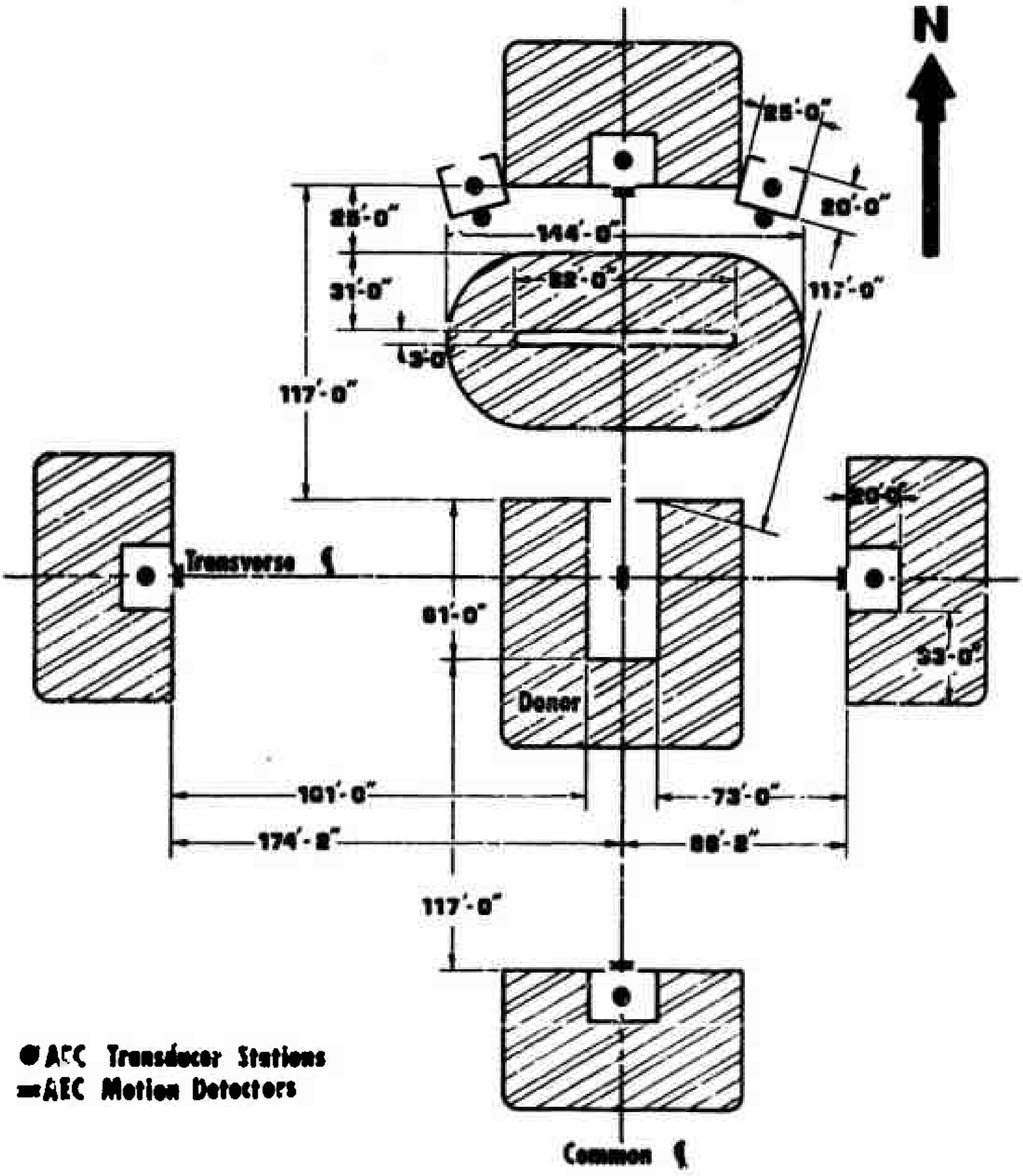
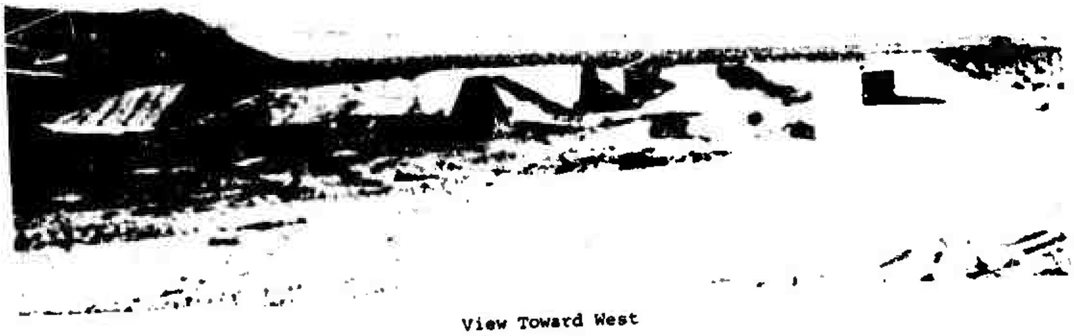


FIG. 1

Plan View Of Eskimo I Test

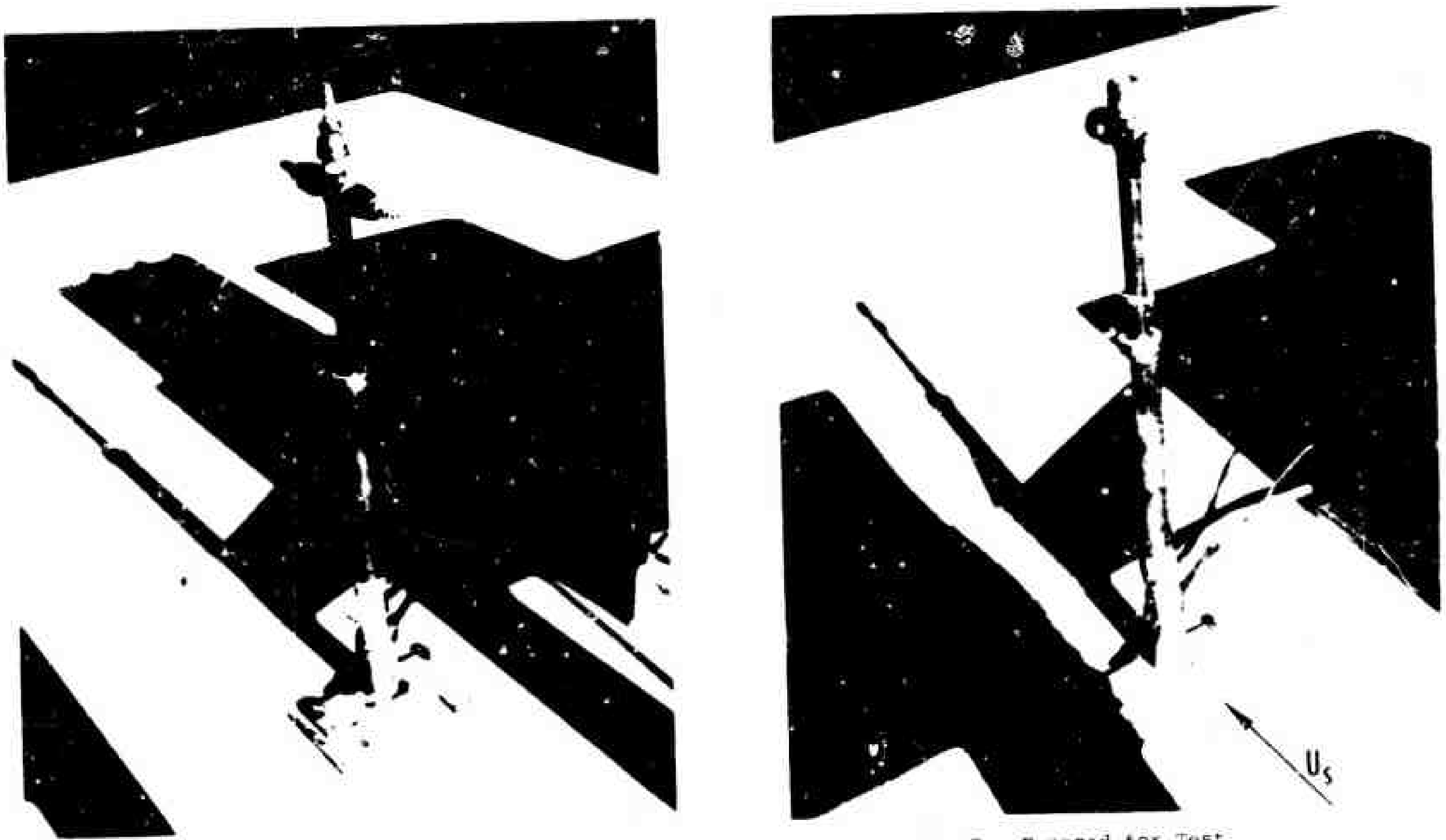


View Toward West

View Toward East

View Toward Northwest

Fig. 2. Pre-Test Views of Eskimo I



A. Fitted for Calibration

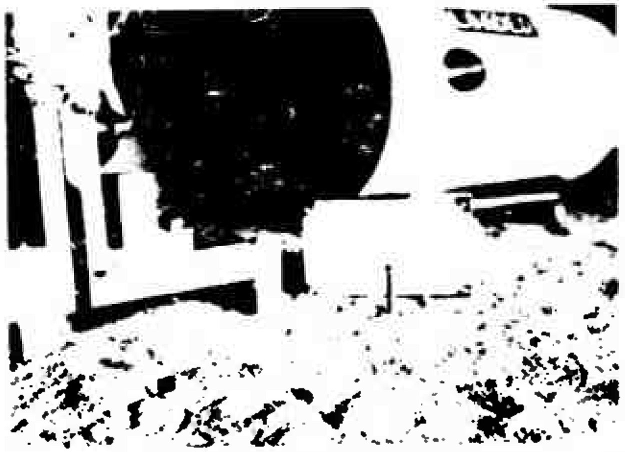
B. Exposed for Test

Fig. 3. Pressure Transducer Array

Shock Motion Detector Atop Donor
Igloo (Zero Time Reference Point)

Shock Motion Detector on Headwall of Acceptor
Igloo (Typical of Four Installations)

Outside Pressure Transducer Location
Near Forward Wall of Blockhouse



Inside Pressure Transducer Location
In Center of Blockhouse Floor

Fig. 4. Shock Motion Detectors and Blockhouse Transducers

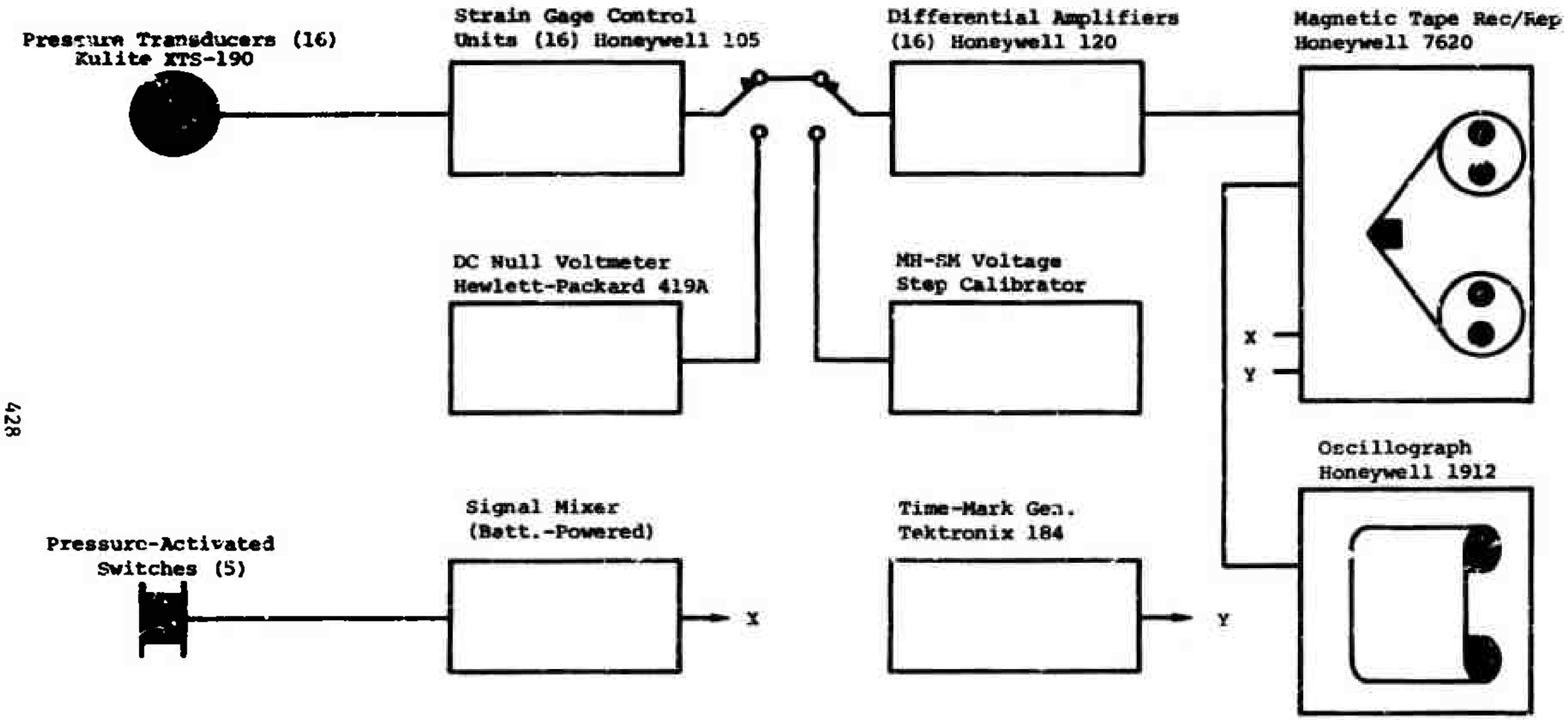
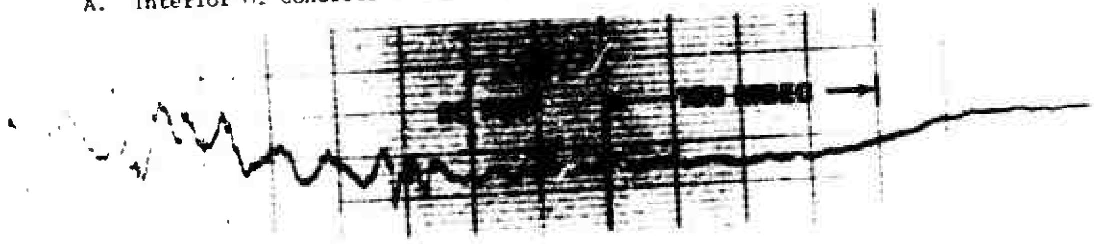
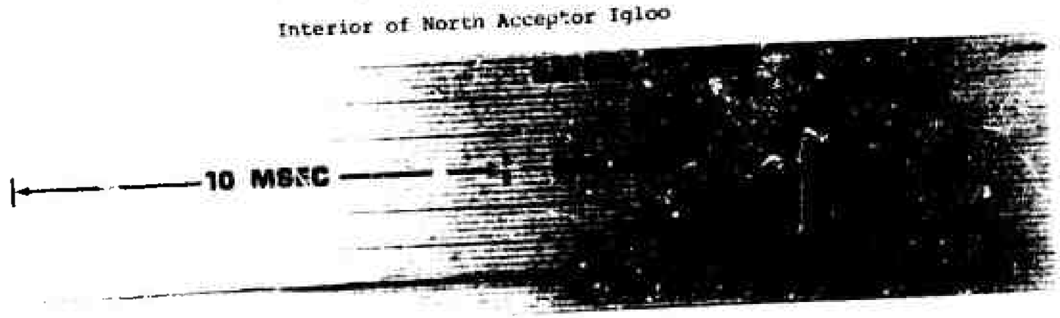


Fig. 5. Block Diagram of Record-Reproduce Instrumentation

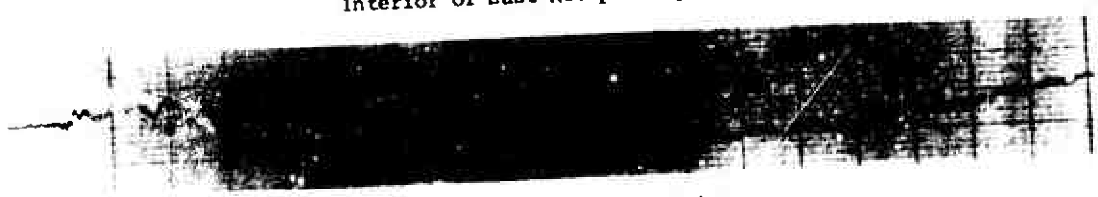
A. Interior of Concrete Blockhouse B. Exterior of Concrete Blockhouse



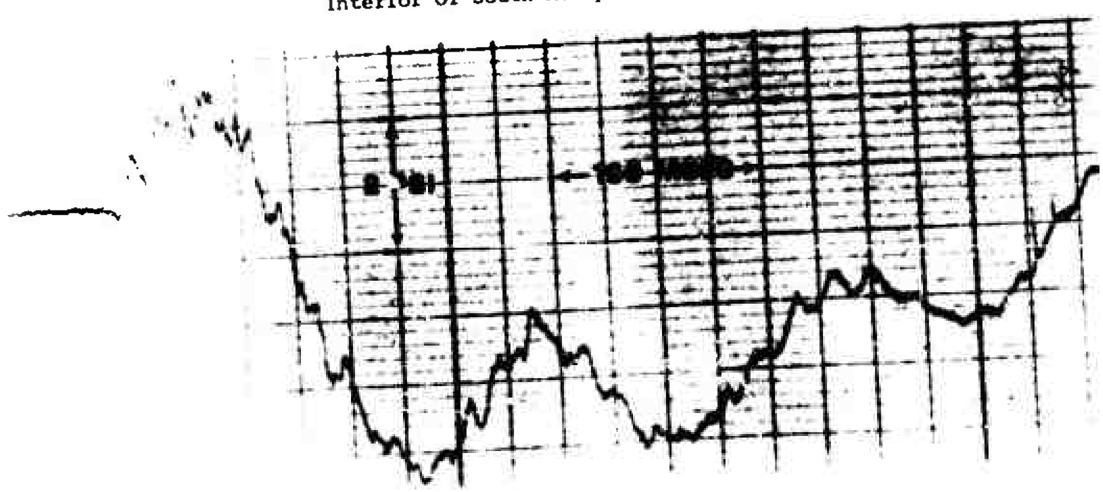
Interior of North Acceptor Igloo



Interior of East Acceptor Igloo



Interior of South Acceptor Igloo



Interior of West Acceptor Igloo

Fig. 6. Pressure Profiles (P_{so})

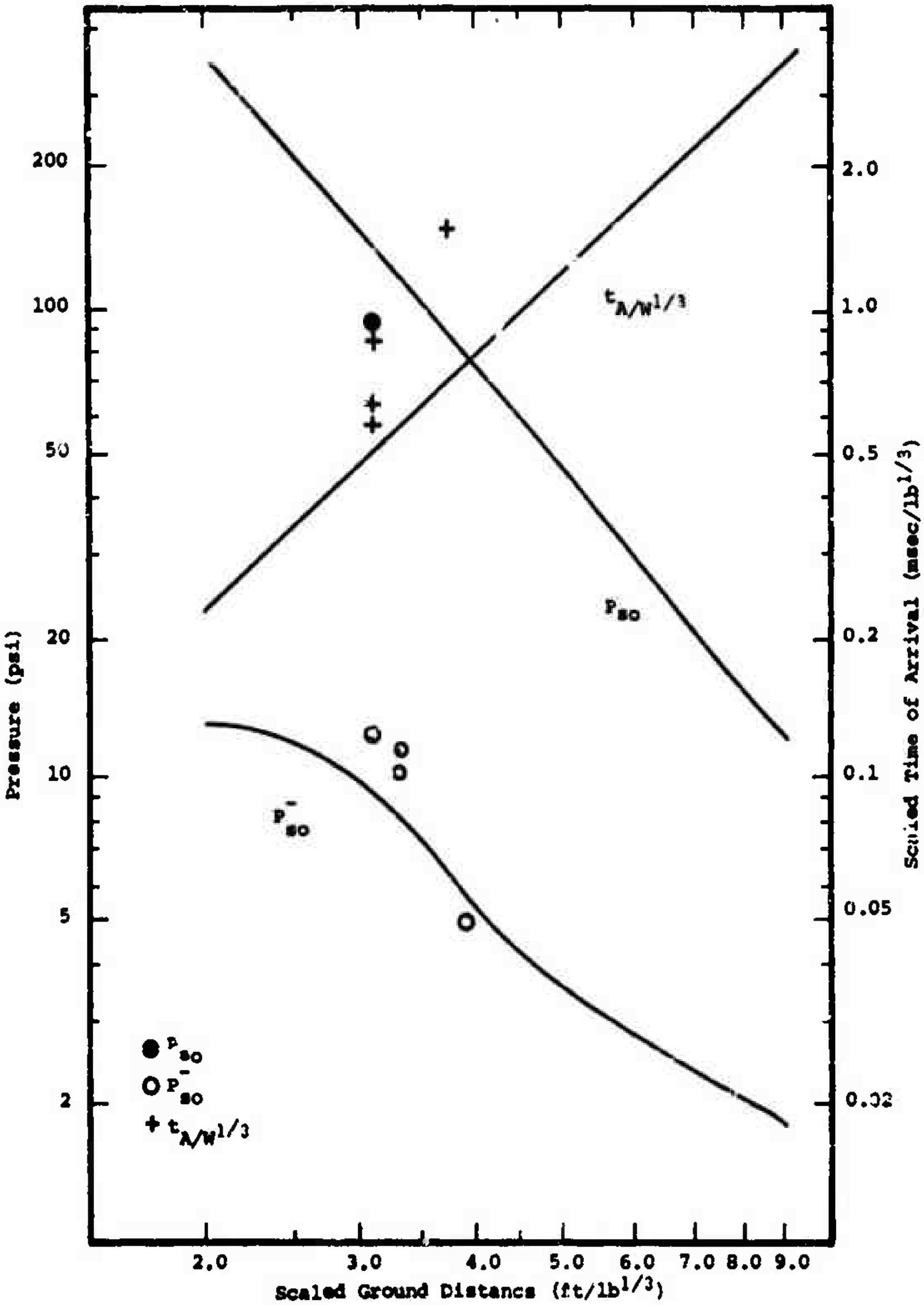
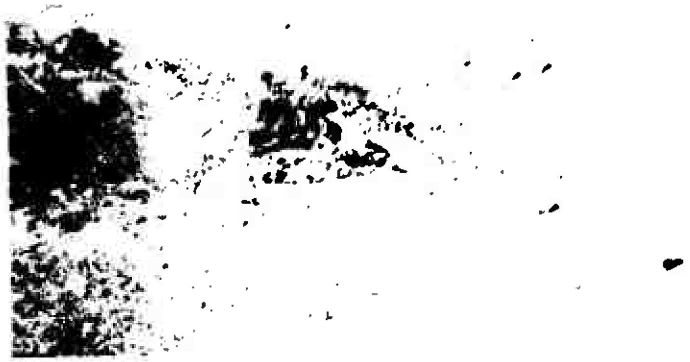


Fig. 7. Comparison of Converted Eskimo I Data with Ideal Surface Burst Curves



Donor Crater - View Toward Earth
Barricade on the North End

Northwest Blockhouse

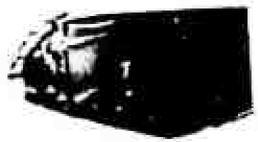
Northeast Blockhouse

Fig. 8. Post-Test Damage - Donor Igloo and Concrete Block Structures

North Acceptor Igloo

East Acceptor Igloo - View Toward East Across Donor Crater

South Acceptor Igloo



West Acceptor Igloo

Fig. 9. Post-Test Damage - Acceptor Igloos

Table 1. Eskimo I Test Data

Ambient Conditions: 936 mbars, 55 F

Location	Distance to Headwall (ft)	Shock Arrival [a] @ Headwall (msec)	Distance to Transducers (ft)	Shock Arrival [a] @ Transducers (msec)	Transducer Orientation	Peak Positive Overpressure (psi)	Positive Phase Duration (msec)	Negative Phase Duration (msec)
N Acceptor	117	23.1	127	27.3	Head-On Side-On Rear-On	31.2 14.8 --	89	276
E Acceptor	73	7.7/10.5 [b]	83	33.9/43.6/44.7 [c]	Head-On Side-On Rear-On	8/303 Saturation Saturation Saturation	Acceptor Units Detonated Transducers Destroyed	
S Acceptor	117	41.0	127	51.6	Head-On Side-On Rear-On	9.2 8.3 7.9	66	373
W Acceptor	161	69.8	171	78.9	Head-On Side-On Rear-On	2.2 2.2 2.3	68	405
NE Concrete Block Magazine	117	25.5 (Calc.)	115	24.3/26.7 [d]	Side-On (Outside)	85.4/187.8 [d]	16	37
NW Concrete Block Magazine	117	--	127	31.9	Side-On (Inside)	59.5	Transducer Destroyed After 10 msec	

[a] *Arrival Time Referenced to Motion Detector Atop Donor Igloo*

[b] *Double Pulse Recorded on E Acceptor Channel; Considered Unreliable*

[c] *Arrival Times and Pressures are Shown for Leakage Pressure, Peak Positive Pressure Preceding Saturation and Saturation, Respectively; Saturation Levels were ~ 700 psi for the Head-On Gage and 350 psi for the Side-On and Rear-On Gages*

[d] *Arrival Time and Peak Positive Pressure for Both Incident and Reflected Waves are Listed*

Table II. Eskimo I Test Data, Converted to Sea Level

Location	Distance[a] to Headwall (ft)	Shock Arrival at Headwalls (msec)	Effective[b] Cube-Root Weight-Surface Burst ($W_{EFF}^{1/3}$ Pos Phase)	Effective[c] Cube-Root Weight-Air Burst ($W_{EFF}^{1/3}$ Pos Phase)	Distance to[a] Transducers (ft)	Peak Negative Pressure (psi)	Effective[d] Cube-Root Weight-($W_{EFF}^{1/3}$ Neg Phase)
N Acceptor Igloo	144	27.2[e]	38	45	153	-11.3	57
E Acceptor Igloo	84	--	--			--	--
S Acceptor Igloo	144	40.0	21	30	153	-10.1	51
W Acceptor Igloo	170	67.7	16	23	179	- 4.8	36
NE Concrete Block Magazine	144	29.6[e]	35	41	142	-12.1	59
NW Concrete Block Magazine	144	--	--		153	--	--

[a] *Converted distance referenced to center of donor*

[b] *Effective cube-root calculations based on converted arrival times, assuming ideal surface burst*

[c] *Effective cube-root calculations based on converted arrival time, assuming ideal air burst*

[d] *Effective cube-root calculations based on converted, peak negative pressures*

[e] *Time off-set approximately 4.9 msec due to detonation asymmetry*

ESKIMO 1

R. G. Perkins
Department of Defense Explosives Safety Board
Washington, D.C.

You have just seen the damage done to igloo doors at minimum separation distances. Also, that this damage resulted in at least one high order detonation of acceptor charges, and two "near misses."

This layout (Figure 1) shows the test configuration for ESKIMO II which the Chairman recently initiated. It is designed to provide us with important confirmation of, or new information on several very important points. The test is designed to use some capital assets remaining from ESKIMO I, Sites A, C, and D, to provide comparisons with that test, and to utilize surplus explosives in a "real world" situation.

First: Igloo door designs. Five igloos with headwalls and doors are to be provided: Igloo A will have a Navy door and headwall structure identical to those in common use at Naval Air Stations and other similar facilities. This door construction was redesigned and strengthened after the ARCO tests in 1945-46 but it has not been proof-tested.

Igloo B will have a headwall and doors identical to those currently specified for U.S. Army Stradley igloos. Figure 2. This will also make use of a steel arch having a cross section approximating that of the Stradley. We hope that it will cut construction costs by 1/3 over present all reinforced concrete construction.

Igloo C will be a newly designed, single-leaf sliding door as an alternate for the A and B designs.

Igloo D will be a simple "fix" which can be applied to doors of existing steel arch magazines if they need to be strengthened so that additional igloos can be built alongside at minimum distances.

The fifth test igloo will be a "control" - identical to those exposed in ESKIMO I except for the length of the arch.

Each test igloo will contain token high explosive acceptor charges and will be instrumented to record the blast pressure and impulse reacting with the doors and headwalls.

The donor charge for this test will be an open barricaded stack of bombs - present plans are that we will use M117, 750 pounders, filled with tritonal. The charge is being designed by BRL and the Board Secretariat to give blast overpressure and impulse values on the headwalls and doors of adjacent acceptors equal to those which would be expected from the detonation of 500,000 pounds of HE in bombs in an earth covered igloo separated from the acceptor or target igloo by $2.0W^{1/3}$.

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Results of past tests, particularly ESKIMO I, have shown that there is a dramatic reduction in the air blast overpressure "yield" from an explosion contained within an igloo as compared with a similar explosion in the open. This reduction in yield increases, the closer the target is to the source.

ESKIMO II should be a final full scale "proof of the pudding" test on

(1) The design of igloo doors to resist overpressure,

(2) Determination of the relative yield of earth covered and open explosions at near-field distances,

(3) The effectiveness of a new concept in using off-the-shelf steel arch components to make a more efficient and less costly magazine than any that are currently standard in the DOD.

Perhaps now you may have questions relative to ESKIMO I, ESKIMO II, or other aspects of the DDESB program. Mr. Fred Weals, NWC Project Manager for these tests is here. LTC Coder, Tom Zaker, Fred and myself will attempt to answer questions which you may have. Thank you.

Figure 1
PROPOSED TEST LAYOUT

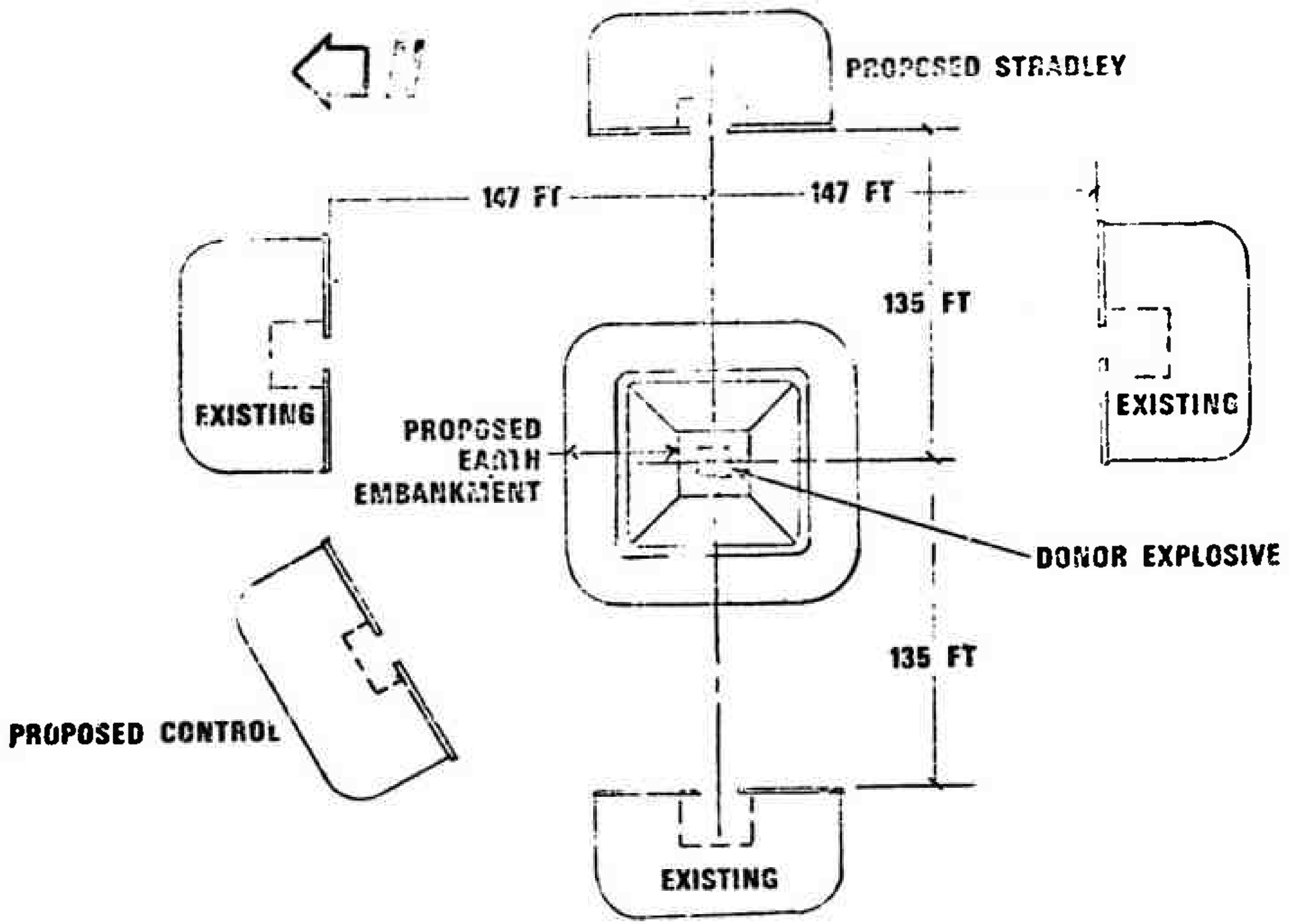
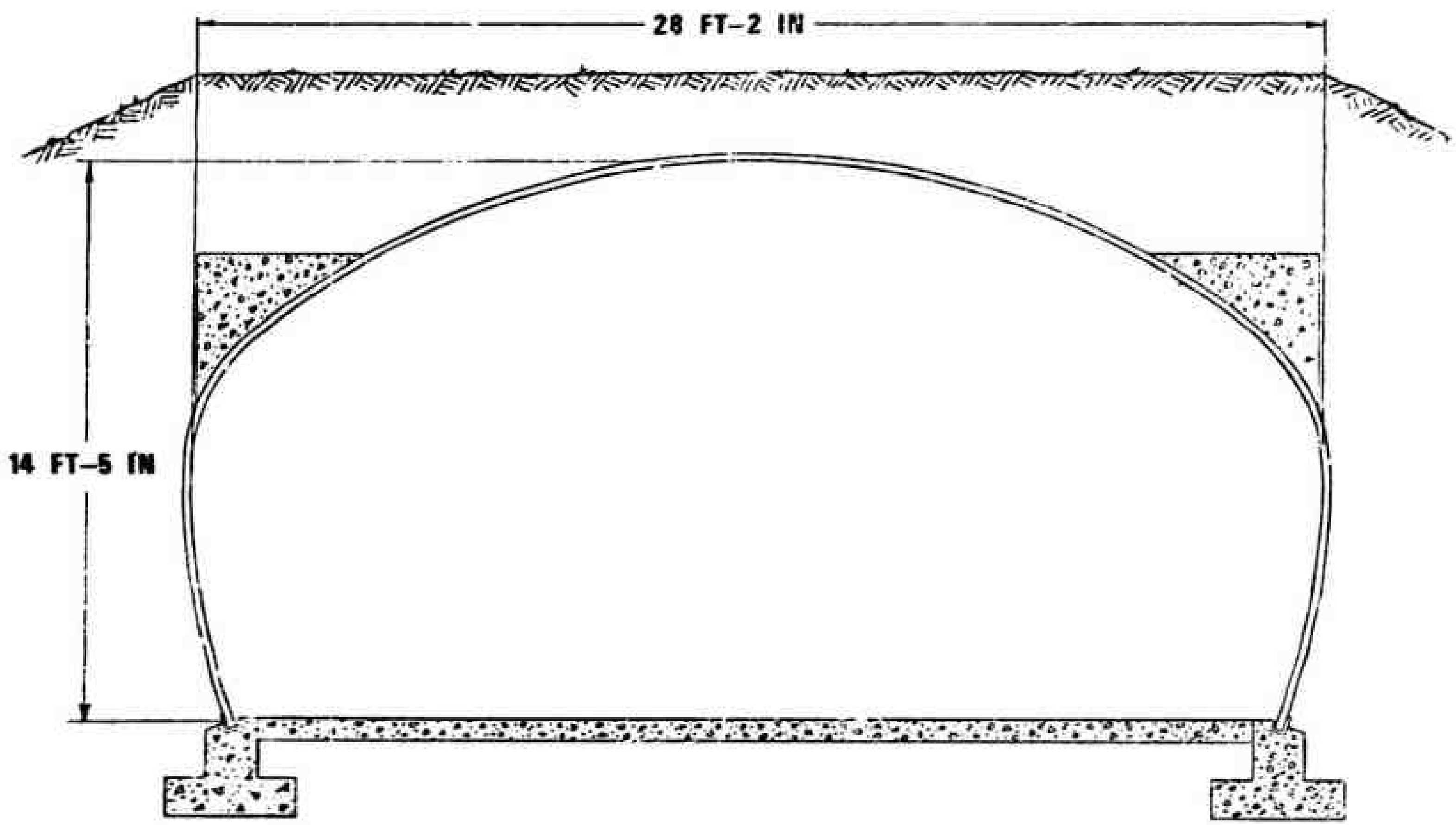


Figure 2

STRADLEY STEEL ARCH



HAZARD ANALYSIS OF THE DDC SYSTEM
FOR A CONTINUOUS TNT MANUFACTURING PROCESS

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ABSTRACT

The application of direct digital control (DDC) to the manufacturing of TNT by a continuous process represents a further step in the munitions facilities modernization program. To evaluate the safety of this operation a hazards analysis of the system is performed. The objective of the study is to assess the magnitude of potential hazards of the system and to identify, rank and catalog possible failure modes and hazardous conditions so that effective corrective measures can be formulated.

Because of the complexity of the system a fault tree analysis (i.e., top down) approach is used in the investigation. The analysis starts with the hazardous condition and proceeds downward to define possible equipment faults and failures, material behavior and human action, the occurrence of which singly or in combination can cause the undesired event. A detailed logic diagram is prepared. It depicts the interrelationship between basic faults and conditions that must occur to result in the hazard. The probability of occurrence of each basic event is estimated and the hazard probabilities are computed. A summary of major faults and estimates of their criticality is then prepared. Reliability analysis techniques are employed in estimating component and equipment subsystem failure rates.

The hazard categories considered in the current application are spills and fires-explosions-thermal excursions. In the latter category an overall plant hazard probability of 0.04 is estimated, assuming a six month continuous operation. It is found that no single event by itself results in a hazardous situation and that the emergency controla of the system have much lower failure probabilities than the direct process controls.

1. INTRODUCTION

The application of direct digital control (DDC) to the manufacturing of TNT by continuous process is a further step in the overall ammunitions facilities modernization program. In order to assure the safety of such an innovation, a preliminary hazard analysis of the system was performed. Its purpose was to identify and evaluate the possible hazards arising from the introduction of direct digital control on a continuous TNT line.

The production of TNT involves three distinct operations. The heart of the process is the nitration section where toluene is converted into crude TNT by reacting with mixtures of nitric and sulfuric acids. The crude TNT is then purified by washing with water and treatment with sodium sulphite (sellite) to remove entrained acid and undesirable TNT isomers. Finally the TNT is transferred by pumping to a finishing area where it is separated, dried, flaked and packaged. In a continuous production both the nitration and purification operations are basically counterflow processes. The nitration section contains six nitrator/separator stages of which stage 1 and 3 have two nitrators. Toluene is metered into Nitrator 1A where it is converted to mononitrotoluene. The nitrobody is separated and flows to the next higher nitrator. Thus it proceeds through each nitrator leaving the final stage as crude TNT. Oleum is fed into nitrator 6 and moves in the opposite direction to the nitrobody through each unit becoming more diluted until it leaves the process as spent acid. To perform the nitration, nitric acid is added to each stage. Strong nitric acid is fed to nitrators 6, 5, 4 and 3A, while wesk nitric acid is added to the lower stages. The heat generated in the nitration reaction, which constitutes one of the primary hazards in the process, is removed by cooling coils through which cold water is passed. Agitators in the nitrators assure mixing of the reagents and also provide the driving force for the countercurrent flow. Extensive instrumentation allows for

constant temperature, feed and cooling control; and dumping valves permit the discharge of the nitrator contents into a drowning tank in case of an uncontrollable temperature rise. Purification of TNT takes place in a molten state. First the TNT is washed in a mixer-settler acid washer unit. It is then treated by sellite in two stages to remove impurities and finally is given additional countercurrent washes in the postsellite washer.

Hazards arising out of the control of the process by means of digital computers were the primary concern of this study. The direct digital control system for this application consists of the following equipment and software subsystems.

DDC Computer and Software
Main Data Bus
Supervisory Computer and Software
Auxiliary Data Bus

Some of the features of the system include: data acquisition and control programs, supervisory or direct digital control capability, sequencing programs which can manipulate set-points, operator communication with process and digital system, self-checking of the digital process, manual override for control valves, capability to program startup and shutdown procedures, program operations that allow scientific computations and on-line FORTRAN program development. An accurate description of the system is provided in Reference 1. Here it should suffice to say that redundancies and interlocks have been built into the overall system to provide for a safe operation.

In the following section of this paper the methodology used in the hazards analysis is outlined. Highlights of the results obtained are then given and this is followed by a brief discussion of the findings.

2. METHOD OF ANALYSIS

After some familiarization with the DDC system under consideration, it was concluded that due to the complexity of the system the only viable approach in a hazards study is by means of fault tree analysis. Due to the preliminary nature of the effort the analysis was restricted to those areas of the TNT process affected by computer control. Also the development of the fault trees in most cases was stopped at a fairly gross level. Hence the basic events are usually specified as the failure of some equipment subsystem. The probabilities of failure for these systems were established by gross reliability analysis. Further to simplify the approach a worst case analysis was performed. This implies that whenever an event takes place which may possibly be hazardous it is in fact assumed to be hazardous and it is expected to lead to its worst consequences. Concerning equipment failures, it is assumed that good maintenance practices are employed, thus excluding wear-out failures, and considering only immediate catastrophic failures of parts.

Since the establishment of human error rates is a difficult and time-consuming task most of the accidents which could be caused by human inattentions have been excluded from this preliminary study. Only where the operator constitutes a redundant safety link with the computer control have human actions been considered.

The objectives of a hazards analysis typically are:

- to assess the magnitude of potential hazards in a system.
- to identify, rank and catalog possible failure modes and hazardous conditions so that effective corrective measures can be formulated.

For complex systems the methodology best suited for this task is based on a fault tree analysis concept (i.e., the top down approach). The analysis starts with the hazardous condition

and proceeds downward to define possible equipment faults and failures, human actions, and material behavior whose occurrence singly or in combination can cause this event.

The outputs of a preliminary analysis include:

- A detailed logic diagram that depicts the basic faults and conditions that must occur to result in the hazardous condition(s) under study.
- An estimate of the probability of occurrence for each hazardous condition under study.
- A summary of major faults and estimates of their criticality together with some overall measure of system safety. Where appropriate recommendations of corrective measures and further analysis are made.

The analysis steps of a typical hazards study are given in Figure 1. In case of a preliminary effort the establishment of criticalities is often omitted or restricted to qualitative judgments. The following paragraphs discuss each of the steps in further detail.

2.1 Gross Hazard Identification

The first task in any hazard analysis is a gross identification of the possible hazards of a system. In the TNT manufacturing it is the chemical aspect of the process which constitutes the direct hazard. Both the final material and the intermediate products are explosive in nature. Similarly the raw ingredients such as strong acids and toluene are hazardous to humans. Finally, the process itself, particularly its nitration part, provides a great element of danger in that a large amount of heat is released in the reaction. Thus, unless properly controlled this reaction can lead to severe thermal excursions or explosions.

A guide to the hazards which may occur in a continuous TNT production line is provided by past operating experience (References 2 and 3). This information led to the definition of three broad hazards classes for the purposes of this study: (1) toxicity, (2) spills and (3) fire, explosion and thermal

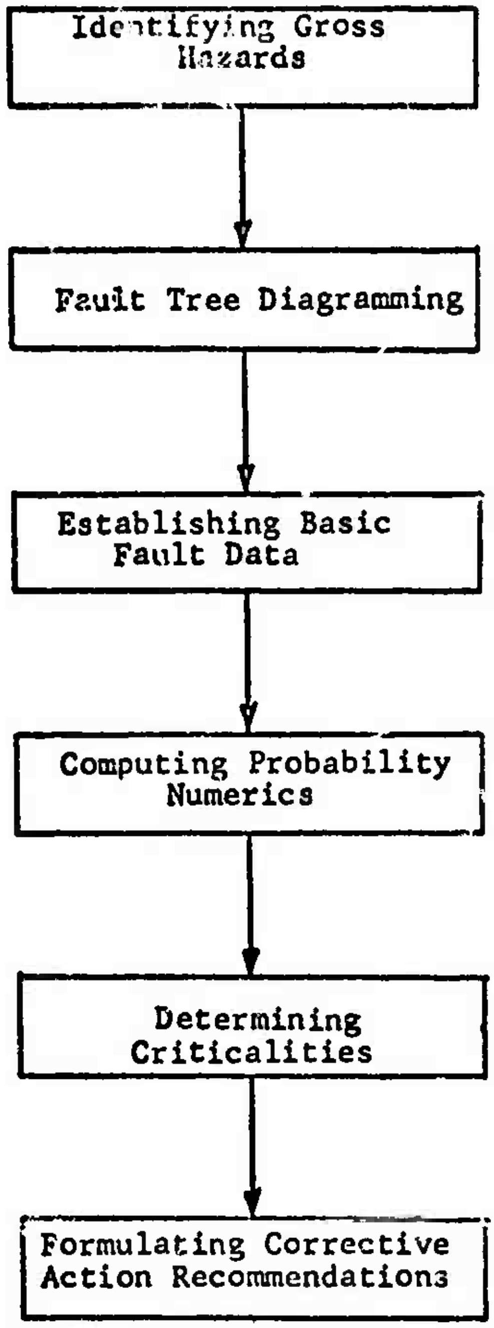


FIGURE 1 ANALYSIS STEPS

excursion. Toxic effects were eliminated from the preliminary analysis since they have little or no connection with the direct digital control of the process. Similarly the finishing area of the TNT process, though containing some of the most hazardous operations (Reference 3) was not included in the study since it is not under computer control.

The broad category of fire, explosion and thermal excursion includes all possible reactions which may occur throughout the process. Thus included are actual detonations, excursions due to mixing of incompatible ingredients such as water into acid, and rapid release of heat, e.g., in a nitration vessel. A finer breakdown in this category would require a much more detailed analysis of the process chemistry and was not warranted in the preliminary study.

2.2 Fault Tree Diagramming

The next step in the hazard analysis is to develop a detailed logic diagram that portrays the combination of events that may lead to the hazardous condition under study. All events (i.e., component faults, human errors, operating conditions, material response, etc.) that must occur to result in the defined hazardous condition are interconnected through basic logic elements ("and" gate, "or" gate, etc.) systematically to form the fault tree. The fault tree symbols and a representative logic configuration are shown in Figure 2.

Having a knowledge of the system, its operation, equipment, human interaction and material behavior of the fault tree is developed, beginning with the defined hazardous condition and proceeding downward with a series of engineering judgments to define basic input events that lead to higher events. This logic structuring process continues until each input event chain has been terminated in terms of a basic fault. When the fault tree structure is complete, the undesired event is completely defined in terms of:

(a) basic faults (hardware and human) whose occurrence alone or in combination can result

AN EVENT, USUALLY A FAULT, RESULTING FROM THE COMBINATION OF MORE BASIC FAULTS AND/OR CONDITIONS AND WHICH CAN BE DEVELOPED FURTHER.

A BASIC FAULT (USUALLY A SPECIFIC CIRCUIT, COMPONENT OR HUMAN ERROR) WHICH CAN BE ASSIGNED A PROBABILITY OF OCCURRENCE.

A FAULT NOT DEVELOPED FURTHER AS TO ITS CAUSES BECAUSE OF LACK OF INFORMATION, TIME, OR VALUE IN DOING SO.

AND GATE - THE OUTPUT EVENT OCCURS ONLY WHEN ALL OF THE INPUT EVENTS ARE PRESENT.

OR GATE - THE OUTPUT EVENT OCCURS WHEN ONE OR MORE OF THE INPUT EVENTS ARE PRESENT.

INHIBIT GATE - SIMILAR TO AN AND GATE, HOWEVER, USED TO INCLUDE APPLICATION OF A CONDITIONAL EVENT.

AN EVENT EXPECTED TO OCCUR IN NORMAL OPERATION.

CONNECTING SYMBOL TO ANOTHER PORTION OF THE FAULT TREE DIAGRAM.

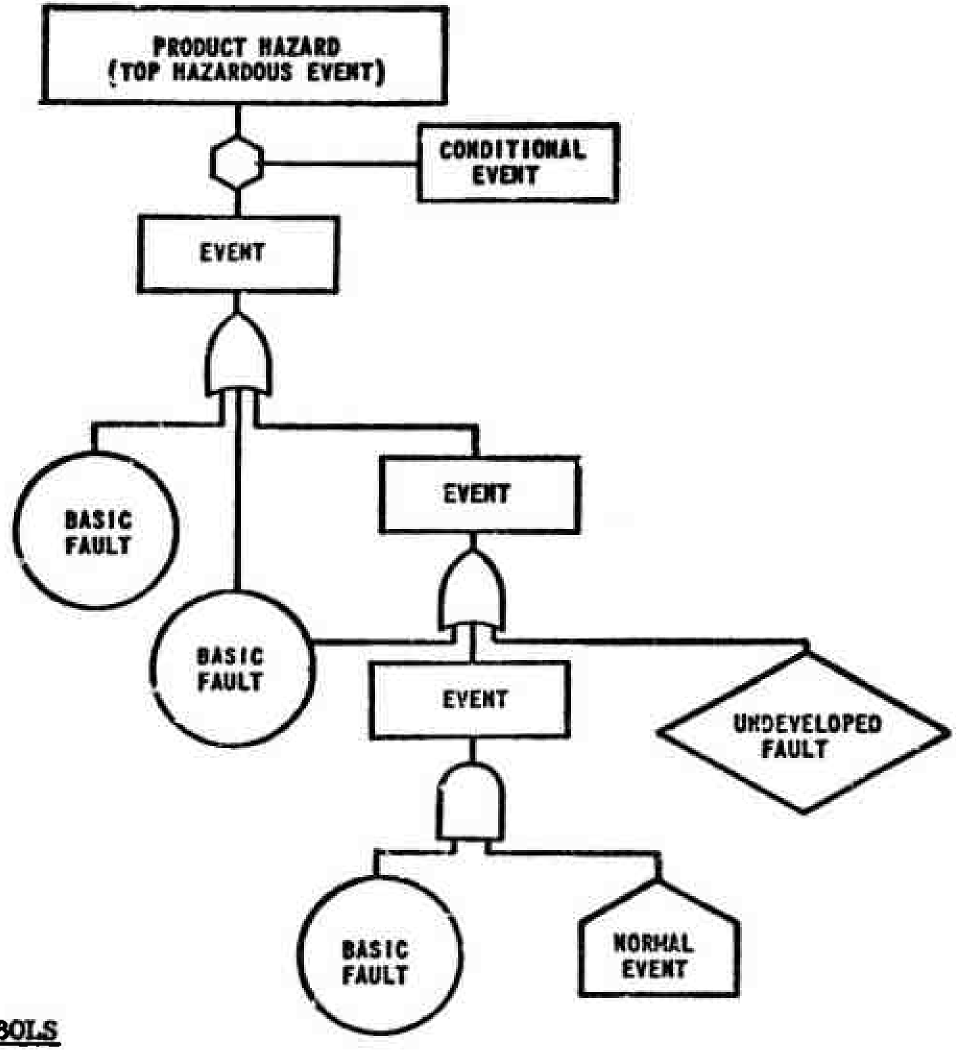


FIGURE 2. FAULT TREE SYMBOLS

in the defined hazard regardless of their apparent frequency of occurrence,

(b) independent input events; and

(c) basic faults (e.g., component failure modes) for which failure rate data are available or may be estimated.

2.3 Collecting Basic Fault Data

After the fault tree has been structured, the next step in the analysis process is to estimate failure rate data for each basic fault that comprises the fault tree. Failure rate data are necessary input for determining occurrence probabilities. For a preliminary analysis, these data consist of estimates of component failure rates, material sensitivity information, and human error rate data. Component failure rates are obtained using gross reliability analysis techniques while material information is primarily obtained from data available in the literature. Since human error rates are difficult to establish, they are simply obtained for purposes of a preliminary analysis by means of subjective estimates, using the operating experience at similar facilities.

2.4 Probability Numerics

The next step in the analysis process is to compute probability numerics. This involves computing the occurrence probabilities for all basic faults, events, and hazardous conditions (top faults) based on the combinatorial properties of the logic elements in the fault tree. The output event probabilities are computed, starting with the lowest levels and continuing to the highest levels in the tree.

Computation:

<u>and gate</u> $$P(A) = \prod_{i=1}^{n} P(X_i)$$

<u>or gate</u> $$P(A) = 1 - \prod_{i=1}^{n} \left[1 - P(X_i)\right]$$

where:

$P(A)$ = output probability

$P(X_i)$ = probability of the ith input

n = number of inputs

2.5 Criticality Estimates and Recommendations

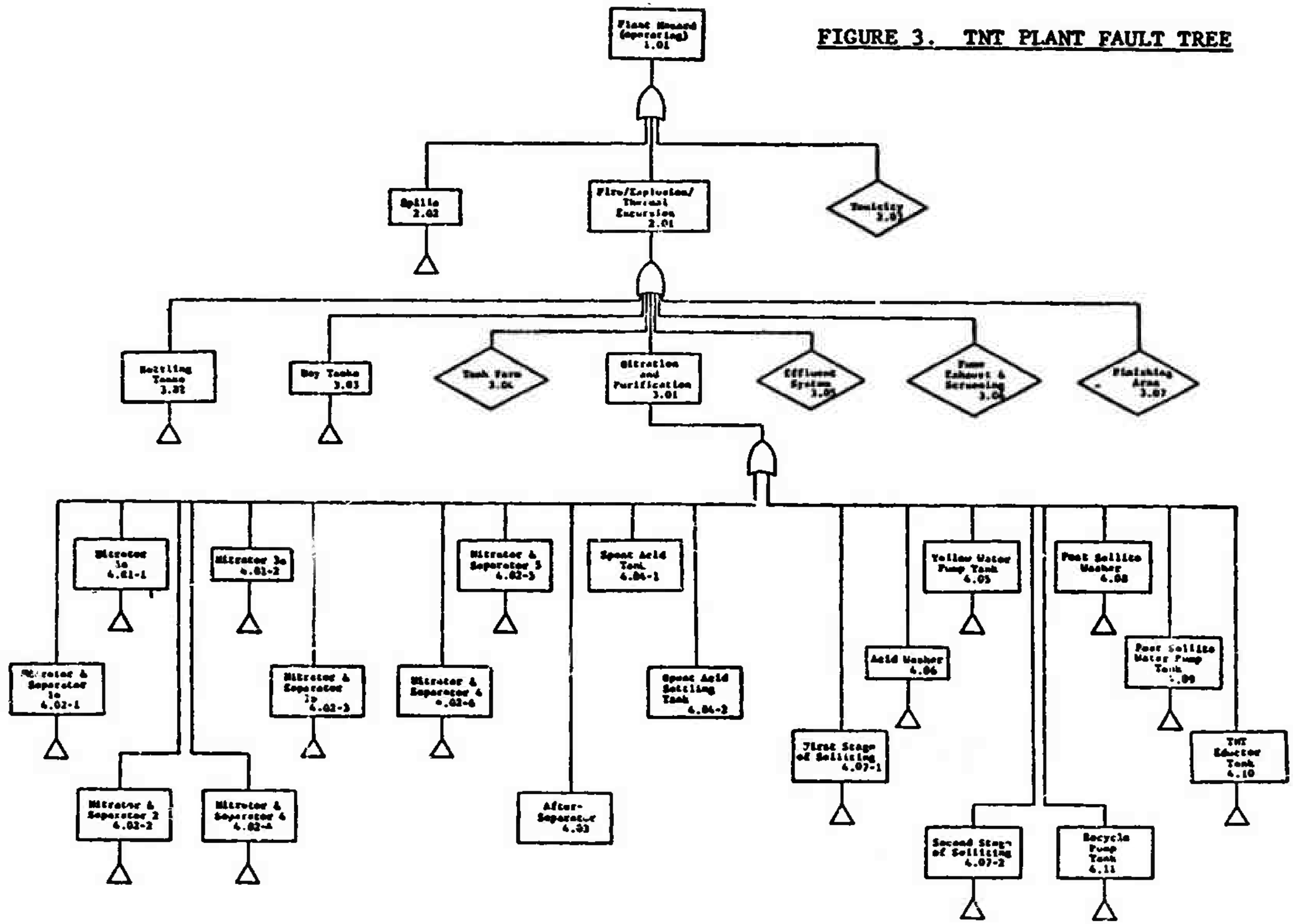
After the occurrence probabilities have been computed, the criticality of all basic faults may be evaluated. Criticality is a measure of the relative seriousness of the effects of each fault. In a preliminary analysis this involves qualitative engineering evalustion and provides a basis for fault ranking. Finally after all of this data has been summarized, recommendations for corrective action and/or additional study can be made.

3. FAULT TREE DIAGRAMS

Using the approach outlined in the preceding section, fault tree diagrams were prepared for the continuous TNT production process under direct digital control. The diagrams essentially represent an analysis of the "Run" or steady state operating phase of the process and are limited to a single TNT line. The level of detail into which operations are broken down is indicated in Figure 3, which represents the fault tree for an overall plant hazard. Each of the significant equipment items appearing in each part of the process is considered. Items indicated by a diamond symbol in the fault tree are not further developed in the analysis and have no bearing on the overall plant hazard as considered in this paper. The triangle continuation symbol indicates that this fault is further developed in succeeding diagrams. Figure 3 shows all the items in the nitration and purification section of the TNT line which are considered in this analysis. Similar breakdowns of the other plant areas were also prepared.

Simplifications were introduced into the analysis due to its preliminary nature, e.g., all fires, explosions and

FIGURE 3. TNT PLANT FAULT TREE



excursions were lumped into one category. A single fault tree diagram was prepared where similarity of operation and control exists for a number of equipment items. Also where overflows are provided spills were considered nonhazardous.

Figures 4 and 5 represent the detailed fault tree for a thermal excursion hazard of a typical nitrator. We find that such excursions will occur either due to a failure to dump the nitrator in an emergency, or due to agitator impact on the draft tube after dump. The required control and process failures leading up to these events are detailed in the diagrams. Figure 6 illustrates the hazardous spills throughout the plant. Detailed fault tree diagrams for all items indicated in Figures 3 and 6 were prepared. It was found that the major hazards in the nitration section of the plant are associated with the chemical reaction and nitrobody formation. In the purification and tank sections of the plant shock and impact hazards predominate.

4. HAZARD PROBABILITY ESTIMATES

The preliminary hazard analysis of the TNT process was primarily equipment and control oriented. Thus the majority of basic faults appearing in the fault tree diagrams represent equipment subsystem failures. Analytical reliability prediction techniques were used to determine various performance probabilities of the control systems identified on the fault tree diagrams. This involved determining a reliability numeric for each system based on gross part counts and the general application of part failure rates. The resultant data, then, provided a basis to estimate fault probabilities. Other basic event probabilities were estimated using subjective engineering judgments, based on the complexity of the systems or possibility of human error.

FIGURE 4. NITRATOR FAULT TREE

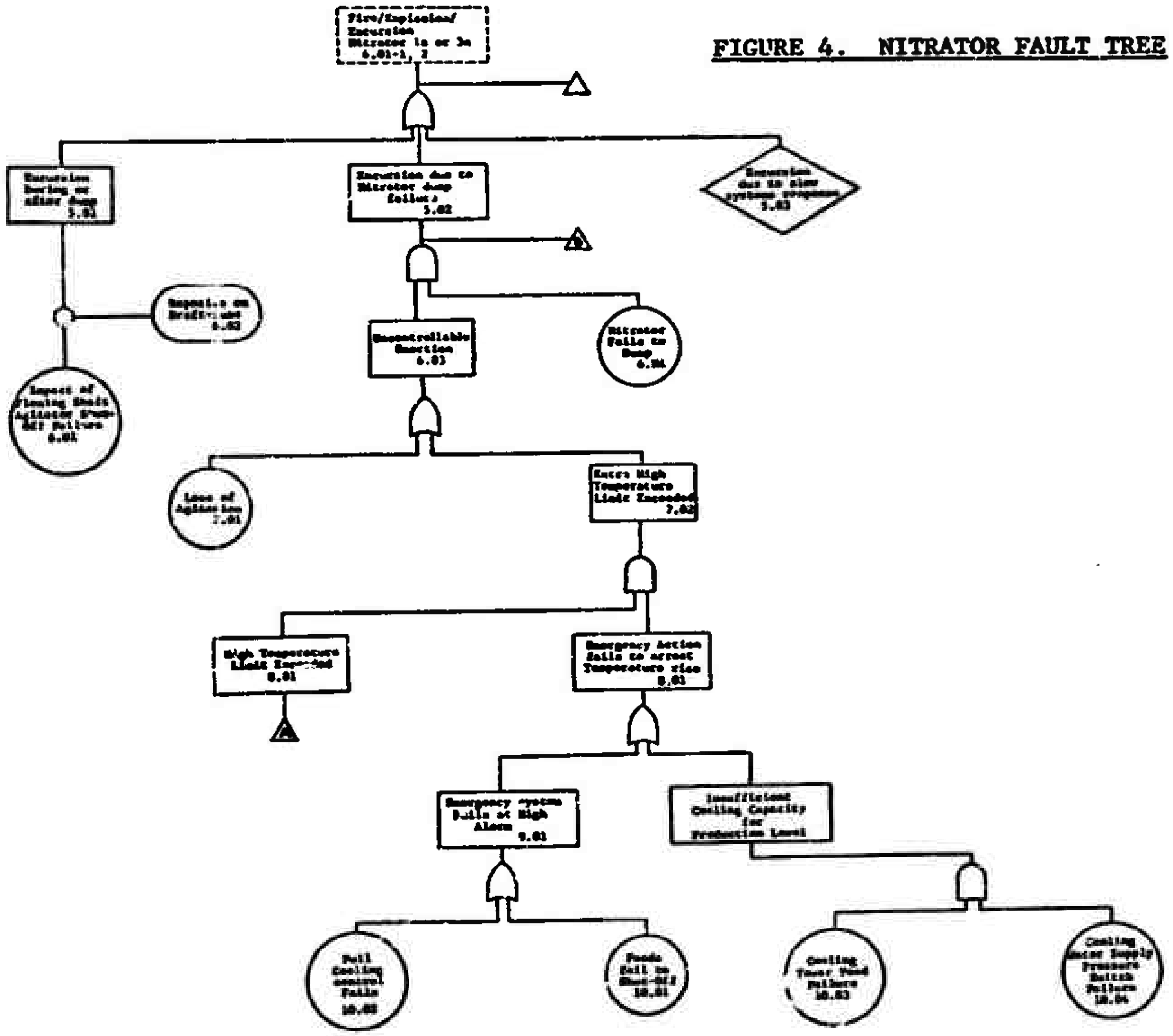


FIGURE 5. NITRATOR FAULT TREE CONT.

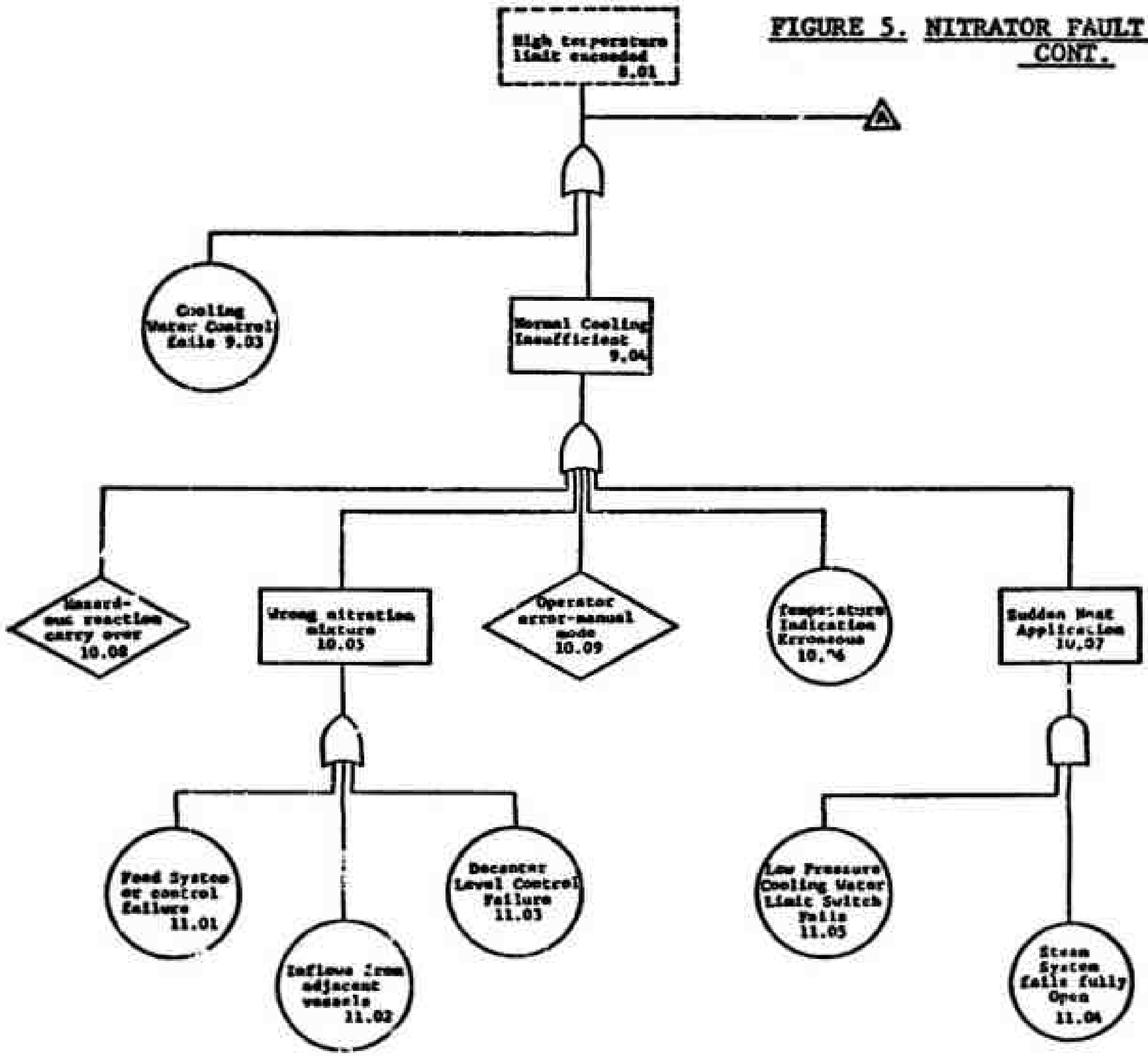
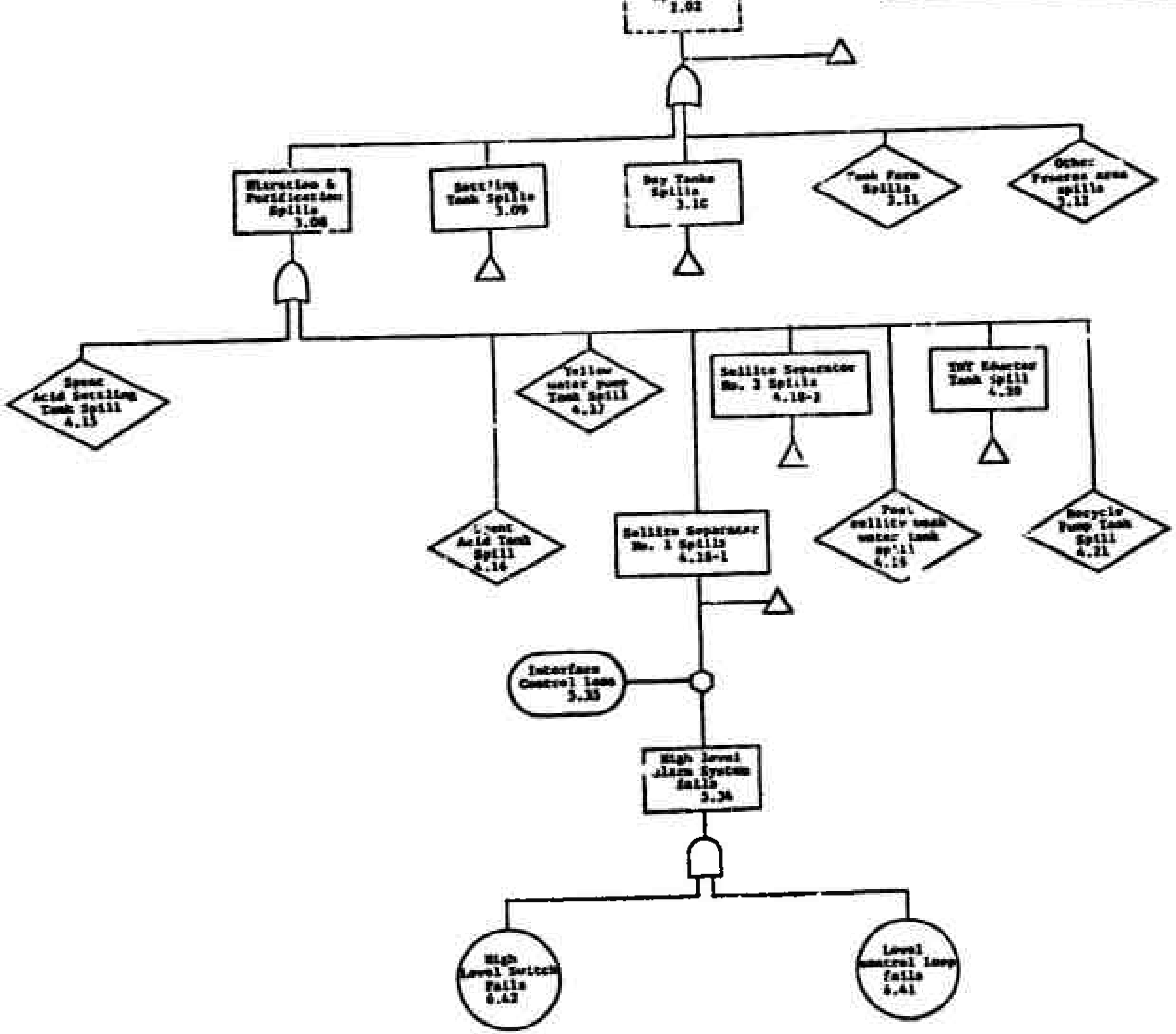


FIGURE 6 SPILLS FAULT TREE



The basic assumptions and ground rules used for this analysis were as follows:

(1) It was assumed that design failures have been eliminated and that system failures are a reflection of part failure; i.e., system reliability is dependent upon each part of the system.

(2) The exponential failure distribution was assumed valid.

(3) The analysis was based on generic part failure rates and part count prediction techniques.

(4) The basic generic part failure rates were derived from military sources (References 4 and 5) and supplemented with subjective engineering estimates (see Table I). Included in the estimated failure rates for the mechanical parts were adjustments to account for usage factors and various applications considerations.

(5) In general, an overall continuous operating period of six months (4400 hours) was used to determine system reliability. This assumes that the functional integrity of each control system is assured for this time period through an effective program of preventive maintenance.

(6) An operating time base much less than six months ($\ll$ 4400 hours) was used to determine the reliability of the full cooling water system. This is because full cooling is only activated under emergency conditions.

(7) The concept of availability was used to determine probability numerics for certain redundant equipment where repair can be effected without interrupting the TNT production process.

(8) The reliability associated with 115 V.A.C. power was not considered in this preliminary analysis. Since it was evident that its availability would be much higher than the reliabilities of the equipment elements that comprise the control systems.

Figure 7 presents the reliability block diagram for the nitrator dump system. Similar diagrams were developed for the other control systems. They define the scope of the analysis and provide the basis for formulating system probability models. The diagrams are intended to reflect the reliability connectivity between the various elements (i.e., valves, sensors, control instruments, etc.) that comprise the system.

<u>TABLE I</u>

<u>ESTIMATED GENERIC PART FAILURE RATE</u>

Part	Failure Rate, λ (%/1000 hrs.)
Transistor, switching	0.01
Transistor, linear, power	0.20
Transistor, linear, low power	0.10
Diode, switching	0.01
Diode, power	0.03
Diode, zener	0.05
Diode, linear	0.02
Resistor, carbon comp.	< 0.01
Resistor, film	< 0.01
Resistor, wire wound	0.02
Capacitor, mylar	0.01
Capacitor, ceramic	0.01
Capacitor, electrolytic	0.03
Microcircuit, digital	0.04
Microcircuit, linear	0.10
Transformer, power	0.03
Coils	0.01
Relay, control	0.01
Relay, time delay	1.8
Switch, pushbutton	0.32
Switch, temperature	1.3
Battery, rechargeable	1.0
Valve, solenoid	0.1
Valve, manual	0.1
Valve, pneumatic	1.0
Pressure regulator	1.0
Operator error	0.25

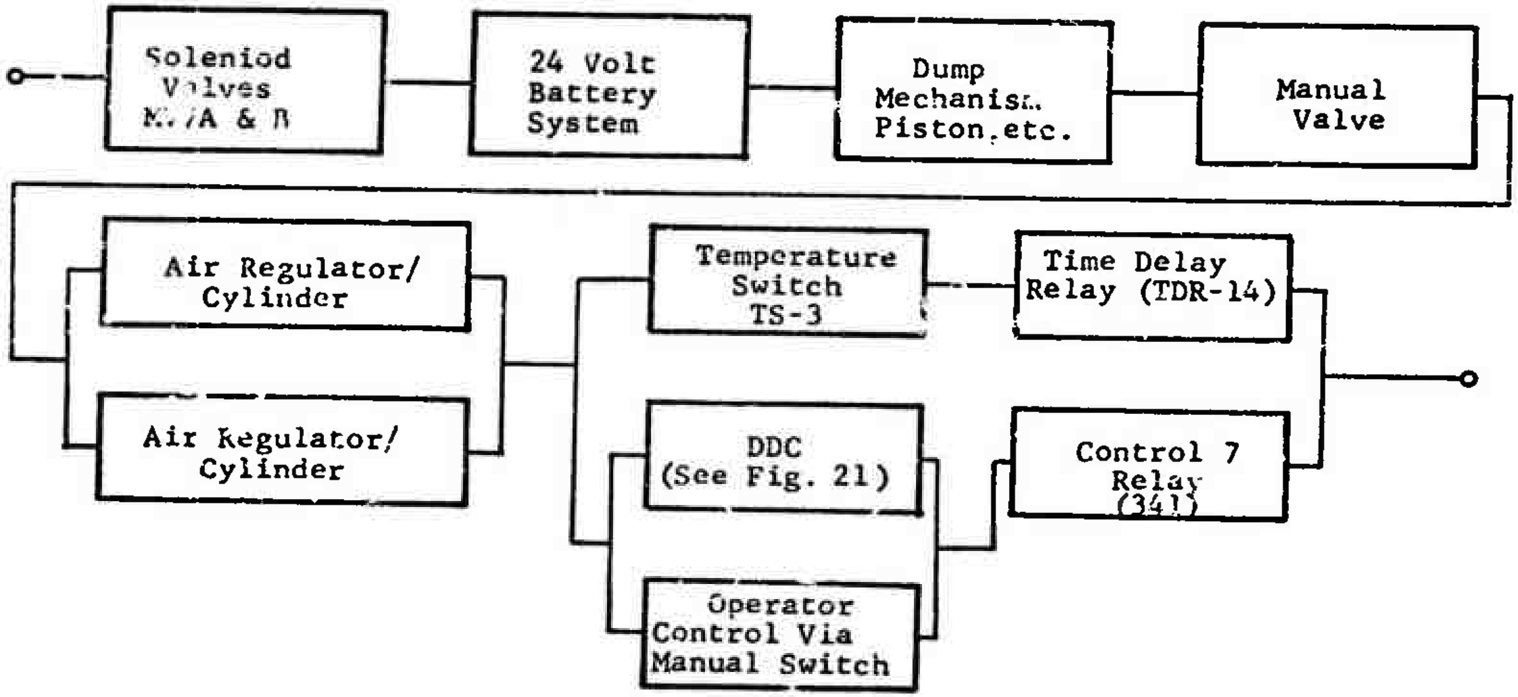


FIGURE 7 DUMP SYSTEM-RELIABILITY BLOCK DIAGRAM

When functionsl blocks are connected in series the failure of any one of the blocks causes the system to fail. For parallel connection both (or all) blocks must fail to cause system failure. For example, Figure 7 shows that there are three redundant switching pathways to initiate a dumping action. Details of the DDC system as it pertains to the dumping of a nitrator are given in Figure 8.

The reliability of each control system was computed from probability expressions derived from the block diagrams and the estimated block failure rates. The results of these computations for all considered control subsystems are summarized in Table II. The results of the control system reliability analysis were then used to define the probability of occurrence of the basic events as presented in the fault tree diagrams. The probability of failure P_f is simply defined in terms of reliability R as $P_f = 1 - R$. These results were supplemented by subjective judgments for the estimation of the other basic event probabilities for which no readily derivable reliability data exist.

5. RESULTS AND DISCUSSION

Based on the logic of the fault tree diagrams and the numerical probabilities of the basic events, probabilities for the secondary or higher events were computed. The results are summarized in Table III, which presents the hazard probabilities for all the major equipment areas and items included in the analysis, as well as estimates of the overall plant hazards both for spills and the fire-explosion-excursion category. The designation "Excursion" in the table refers to any explosion, fire or thermal excursion hazard. It should be remembered that the input numerics of these calculations are based on the reliability estimates. Thus a six month continuous operating period is assumed and the hazard probabilities of Table III reflect this time span.

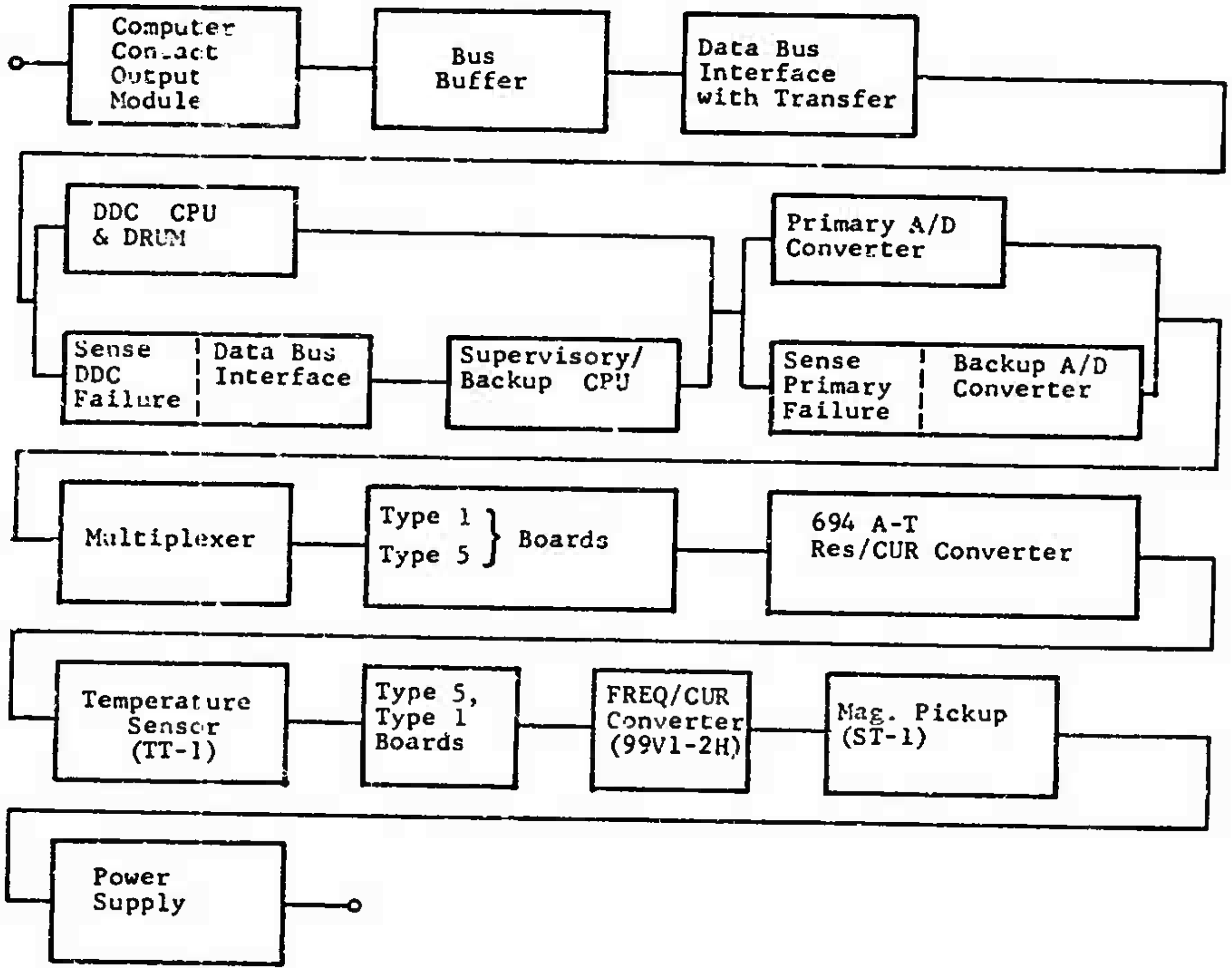


FIGURE 8 DDC (DUMP SYSTEM) RELIABILITY BLOCK DIAGRAM

TABLE II

SUBSYSTEM RELIABILITY ESTIMATES

Subsystem	Reliability
Dump System	0.98
Agitator Speed Control	0.90
Agitator Shutoff	0.93
Feed Shutoff	0.99
Full Cooling Water	0.99
Cooling Water Control	0.40
Steam Control	0.95
Feed Control	0.01
Level Control	0.36

TABLE III

SUMMARY OF HAZARD PROBABILITIES

Event No.	Hazard Description	Hazard Probability
1.01	Plant Hazard	0.0816
2.01	Fire/Explosion/Thermal Excursion	0.0417
2.02	Spills	0.0399
3.01	Excursion-Nitration & Purification	0.0405
3.02	Excursion-Settling Tanks	0.0004
3.03	Excursion-Day Tanks	0.0008
3.08	Spills-Nitration & Purification	0.0023
3.09	Spills-Settling Tanks	0.0132
3.10	Spills-Day Tanks	0.0244
4.01-1,2	Excursion-Nitrator 1a or 3a	0.0039
4.02-1 to 6	Excursion-Nitrator with Separator	0.0040
4.03	Excursion-After Separator	$<10^{-4}$
4.04-1,2	Excursion-Spent Acid Tanks	0.0002
4.05	Excursion-Yellow Water Pump Tank	$<10^{-4}$
4.06	Excursion-Acid Washer	$<10^{-4}$
4.07-1,2	Excursion-Sellite Washer-Separator	$<10^{-4}$
4.08	Excursion-Post Sellite Washer	$<10^{-4}$
4.09	Excursion-Post Sellite Water Pump Tank	$<10^{-4}$
4.10	Excursion-TNT Eductor Tank	0.0075
4.11	Excursion-Recycle Pump Tank	$<10^{-4}$
4.12-1 to 4	Excursion-Settling Tank	0.0001
4.13-1 to 4	Excursion-Day Tank	0.0002
4.18-1,2	Spill-Sellite Separator	0.0004
4.20	Spill-TNT Eductor Tank	0.0015
4.22-2,3	Spill-Settling Tank	0.0066
4.23-1 to 4	Spill-Day Tank	0.0061

The data indicate an overall plant hazard probability of around 8.16 percent. This then is the probability that in six months of continuous operation a spill, fire, explosion, etc., will occur throughout the plant areas analyzed. Of this total about 4 percent represents the probability of hazardous spills while the probability of an excursion is around 4.17 percent. Of this latter number most of the hazard is accounted for in the nitration and purification area of the plant (see events 2.01 and 3.01 in Table III). While these overall plant hazard probabilities may appear to be high, one should keep in mind the complexity of the system and that these numbers represent a six month period of continuous operation. As should be expected the nitrators represent some of the largest hazards (see Events 4.01 and 4.02). The single highest hazard probability was computed for the TNT eductor tank (Event 4.10). However, the frequency of occurrence of all of the items contributing to this hazard are largely based on subjective judgment. Since pure TNT is stored in this tank, very conservative estimates were made.

While explosions caused by impact or hydraulic shock are possible in various settling and pump tanks, the severity and magnitude of such reactions is obviously much less than, say the excursion of a nitrator. Fires in the storage and day tank areas could be quite severe. These most likely would be associated with large spills. The high probability of spill calculated in this analysis is primarily due to the high failure rates predicted for the level controls.

A similar situation exists for the nitrators and separators, where quite high failure rates were predicted for the control of cooling water, feeds, and separator level. Based on this preliminary analysis there exists a virtual certainty (probability close to unity) that the nitrator will exceed the high temperature limit during the six month continuous operation period. The likelihood of exceeding the extra high temperature limit leading to a dump situation is around 0.024.

The single, most severe hazard requiring a nitrator dump is the loss of agitation with a probability of 0.10. Altogether the estimate for an uncontrollable reaction in a nitrator has a probability of 0.124. This together with a failure probability of 0.02 for the dumping system, leads to an excursion probability in a nitrator of 0.00248. The probability of an excursion being initiated in the nitration section due to other causes is considerably smaller. Also such excursions would be much less severe than a reaction in the nitrator.

The fault tree diagrams show that no single basic fault by itself causes a major system hazard. The numerics of this analysis while preliminary tend to indicate that the emergency controls of the system have much lower failure probabilities than the direct process controls. Two factors contribute to this disparity. First the process controls must perform continuously while the emergency controls are called upon only periodically. Thus the total exposure to failure of the latter controls is less over the same time period. Second, the emergency controls have usually a number of redundancies built into them. This is not the case for the direct or primary controls. While redundancy is provided at the computer level, it is usually omitted in the field equipment, e.g., actuators, valves, etc.

The fault tree analysis as presented above pertained only to the steady state operating phase of the system. Transient system phases encountered in startup or shutdown were only investigated qualitatively. No additional equipment hazards were uncovered in this analysis; however the possibility of human error is expected to be more pronounced in these operations. As a special problem the lack of core parity checking was investigated. It appears that core errors cannot cause the process to go into an unsafe state undetected.

It should also be pointed out that no attempt was made to establish fault criticalities using quantitative techniques.

The fault ranking and conclusions discussed above were obtained by a qualitative examination of the fault tree probability results.

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ACKNOWLEDGEMENT

This work was supported by ICI America, Inc., Volunteer Army Ammunition Plant, Chattanooga, Tennessee. The cooperation and quidance provided by ICI and Foxboro Corporation personnel is very much appreciated.

RISK ANALYSIS

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ABSTRACT

This paper reviews a hazard and risk analysis program and discusses (1) benefits of quantifying hazard and risk analysis, (2) need to express data in probabilistic terms, (3) problems in obtaining realistic and accurate data, (4) limitations of the data, and (5) an example of the application of risk analysis and a typical tradeoff study.

INTRODUCTION

The overall Hercules program, known as Hazard Evaluation and Risk Control (HERC), had its beginning in 1958 as a means of self-preservation. The need arose because of an influx of new potentially hazardous materials, new processes and procedures being employed in propellant development and the inadequacy of the existing experience or qualitative method of assessing hazards or risks of these new materials, processes and procedures. The basis of the qualitative method is the previous experience. The method employs empirical tests to simulate the more severe conditions one might encounter to provide abstract data which are compared to the previously related experience. An example of how the qualitative or experience method is used is shown in Figure 1.

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The abstract test results show the differences in electrostatic sensitivity compared to a standard. From this, it can be concluded X is less sensitive and Y is 40 times more sensitive than the standard, but one cannot conclude whether any of the materials constitute a hazard or not! The basic problem with this method is that a material is used as the standard. It is what we subject a material to that causes a problem; i.e., <u>the process by which a material is manufactured, handled and used</u>. For example, the standard and the <u>X</u> and <u>Y</u> material can be made by three different processes <u>yet</u> the experience method is perfectly willing to compare the three materials as if they are made by identical processes.

To combat this problem, Hercules began in 1958 to develop a means of quantitatively assessing hazards. The first step was to employ a systems engineering approach to predict and avoid failures leading to accidents, plant shutdown, and business interruption. This led to developing design and operating criteria to assist engineers and management in decision making. In the middle sixties, the aerospace industry developed fault tree and computer simulation techniques using high-speed, large capacity computers. These techniques were altered to fit the needs of the HERC progrsm for the more complex processes and have become an integral part of the formalized risk control phase of the HERC program.

HERC PROGRAM

The HERC program is essentially a two-part program consisting of Hazards Evaluation which provides the basic data for the Risk Control part (Figure 2). The program begins with the analytical engineering phase which defines the

problem by establishing the potential failure modes and the environment under which the failures can occur. With definition complete, measurements and calculations are made to determine potentials in engineering terms which include those potentials detrimental to health as well as human behavior effects (Figure 3). The next step is to determine if the process materials and equipment will react to the modes of failure and environmental conditions established in the analytical engineering phase (Figure 4). Whether the materials will burn and, in turn, explode is established also. These data are reduced to the same engineering terms established in the analytical engineering phase. This direct comparison (Figure 5) allows a quantitative safety and economic analysis of individual components of the system; such as pumps, valves, switches or reactors that can cause personnel injury, plant shutdown, fires or explosions. Data generated during this phase are used in the risk control part of the program which includes logic diagrams or math models of processes, individual safety margins, design and operating criteria in engineering terms, definition of the damage potential (fire or explosion) and the effects of humans and the effects on humans (Figure 6).

The risk control part of the program is essentially an optimization of safety, cost, and productivity utilizing the design and operating criteria established in the hazard evaluation. If management does not accept the risk, cost, or productivity rates, then the tools are at hand to achieve the desired optimization.

RISK ANALYSIS

The primary purpose of this paper is to point out the need to express hazard and risk analysis in probabilistic terms, as well as the problems encountered, and limitations that must be placed on such an analysis. To illustrate this methodology, three examples are used. The first is the manual operation of placing a lid on a mixer, with the mode of initiation being the potential impact between the lid and mixer (Figure 7). The second example is the cleaning of a mixer using a scraper whereby the potential mode of initiation is the friction between the scraper and bowl (Figure 8). The third example is the remote operation of a flow control valve where the flexible boot fails causing contamination of the metallic moving parts (Figure 9). The potential mode of initiation is friction within the mechanical linkage of the valve. It is important to remember that the boot must fail first as normal opening and closing of the valve will not cause initiation. The analysis of these three operations is shown in Table I. For example, an enginnering analysis of placing a lid on the mixer--an impact mode of initiation--showed the in-process impact could vary, with 840 ft-lb/sec representing the maximum energy for the "normal" operations. (Accidental conditions could develop energies 2-10 times the normal values.) Material response testing of the material established a threshold initiation level (TIL) of 1,680 ft-lb/sec; i.e., for a given number of trials (20), this material showed no signs of decomposition (initiation). Similar measurements were made for the other examples shown and are expressed in an engineering term of pounds per square inch at a specific operating velocity.

A safety margin is defined as the ratio of the material response to the process potential (material response divided by process potential). This ratio

can vary from a fractional number to a large integer. Any safety margin less than one indicates there is sufficient process potential energy available to initiate the material in question. The failure of the valve boot is an example of a safety margin being less than one. These data also show a low safety margin for placing the lid on the mixer which indicates a need to modify the operation to improve the situation. Safety margins are useful in preliminary analysis work but not all the benefits of a quantitative approach can be realized if the analysis is limited to utilizing simple safety margins, nor are all the questions answered and in some cases misleading conclusions can be reached regarding the severity or non-severity of a potentially hazardous operation. For these reasons, it is necessary to establish the probability that a hazardous event will occur. The simple safety margin analysis assumes all events occur with a probability of 1.0; i..e, all with an equal probability, such is not the case! Also, to correctly assess the probability of an event occurring, the time over which the process is operating or the exposure to the potentially hazardous events must be established. For example, the probability that the average citizen in the U.S. will be killed in a motor vehicle accident increases as the mileage traveled or the exposure increases (Table II). The Department of Transportation statistics show the average person drives or rides in a vehicle 30 miles a day and has a probability of 10^{-6} or one-in-a-million of being killed. As more time passes; i.e., a month, a year and 50 years, the probability increases to 10^{-2} or one-in-a-hundred chance of being killed.

Another requirement to properly assess the hazard potential is the need to establish the probability of material initiation at the in-process potential. This is easily done by extending the threshold initiation or explosion

data using statistical techniques. The initiation probability is illustrated in Figure 10 and is simply the area under the intersection of the upper limit of the in-process potential and the lower limit of energy required for initiation.

Two other requirements for a complete hazards evaluation are (1) the need to consider the entire process or system, whereas the safety margin can only accommodate single events or operations, and (2) simultaneous events must be considered which require the data to be reduced to probabilistic terms. The need for simultaneous events to occur to cause an incident can be illustrated by the old domino theme shown in Figure 11. If the fellow on the left pushes over one of the dominos, it triggers the remaining dominos: however, if one domino is missing or one of the hazardous events does not occur, then the sequence of events is stopped or the incident does not occur. The risk analysis model shown below accommodates these problems in that the probability of the event occurring, the probability that the material will initiate at the in-process potential, the probability that material is present (if material is not present, or C_p is zero, then the occurrence of the event would not cause initiation) and the probability of flame or explosive propagation will occur (occurrence of initiation does not itself constitute an incident) are all considered. Thus:

$$\underline{\text{Probability of Event Occurring}} \times \underline{\text{Probability of Initiation at the In-Process Potential}} \times \underline{\text{Probability of Material Being Present}} \times \underline{\text{Probability of Material Reacting}} = \underline{\text{Probability of Incident}}$$

$$E_p \cdot I_p \cdot C_p \cdot R_p = I_p$$

The probability of an incident is thus evaluated for each subsystem of a system. The sum of the subsystem incident probabilities then becomes the incident probability of the entire system. The incident probability is expressed as a function

of a specific time period and can also be expressed in terms of the loss potential in dollars.

To illustrate this relationship, the previous examples of placing the lid on the mixer, cleaning the mixer and operating a valve with boot failure are shown in Table III in probabilistic terms. Also, the engineering terms are repeated here to orient the reader to the previous discussion of safety margins (Table I) and to remind the reader these engineering terms are an integral part of establishing probabilities and performing tradeoff studies.

Placing Lid on Mixer

The analysis of placing the lid on the mixer shows the probability of 840 ft-lb/sec occurring is 10^{-7} and that the probability of the material initiating at 840 ft-lb/sec is 10^{-5}. The probability of the material being present is 10^{-3} which represents the probability that a human will not perform the routine operation as trained or instructed. In this case, the operator is instructed to wipe the mating surfaces of the lid and mixer before placing the lid on the mixer. (This human factor of 10^{-3} was derived from Hercules operational records and represents a statistical sample of over 750,000 events.) The probability that the material will react explosively is 10^{-2}. Thus, the overall probability that these events will occur simultaneously to cause an incident is 10^{-12} (see Table III).

Cleaning Mixer

The analysis of cleaning the mixer follows the same pattern as above except that the in-process energies and probabilities vary. The event probability is 1.0 because the man is instructed to clean the mixer with a spatula which has an upper limit of 3000 psi due to the compressive yield strength of

the spatula. The operating velocity under normal conditions is 1.0 fps or less. The probability that initiation will occur at 3000 psi @ 1.0 fps is 10^{-3}. The probability that material is present during the clean-up operation is 1.0 because the combustible material must be present or the man would not be cleaning the mixer. The probability of the initiation resulting in a propagating reaction is 10^{-2}, yielding an overall incident probability of 10^{-5}.

Operating Valve With Boot Failure

The failure rate of the valve boot is 10^{-4} for a one-day period. The probability of initiation is 1.0 because the energy produced by the valve far exceeds that required to initiate the material when contamination is present because of boot failure. The probability of material being present is 1.0 because when boot failure occurs, contamination is certain. The probability of a propagating reaction is 10^{-2} and the overall incident probability is 10^{-6}.

It is interesting to note the reversal in priorities when one considers the incident probability as opposed to the simple safety margin approach. Previously, cleaning the mixer had the best safety margin from an initiation viewpoint whereas when the overall probability is considered, it exhibits the highest probability of an incident occurring. Likewise, the valve with boot failure exhibited no safety margin and has a lower probability of an incident occurring than cleaning the mixer. Placing the lid on the mixer has the lowest probability of causing an incident.

Frequency of the Event

An additional important consideration which must be brought to bear on the probability of an incident is exposure or frequency of occurrence. That

is, how often, for a given time frame, does the event occur. This consideration essentially adds a fifth variable to the equation discussed previously. That is:

Probability of Event Occurring		Probability of Initiation at the In-Process Potential		Probability of Material Being Present		Probability of Material Reaction		Frequency of Occurrence or Exposure		Probability of Incident
	X		X		X		X		=	
E_p	$\bullet$	I_p	$\bullet$	C_p	$\bullet$	R_p	$\bullet$	Freq	=	I_p

This concept of exposure or frequency of occurrence is illustated in Table IV. The same three examples are shown with the incident probability and the number of times a specific operation is performed for a day, month and year. The obvious conclusion is that as the frequency increases, the probability of the incident increases. In the case of cleaning the mixer, the probability increased from 10^{-5} (normally an acceptable risk) to a 10^{-1} (generally unacceptable) probability of an incident occurring during a one-year period.

Normally the exposure or frequency effect is considered when establishing the event probability but was shown here for illustrative purposes. The foregoing illustrates (1) the benefits of risk analysis, (2) that one must consider the probabiltiy of (a) the event occurring, (b) initiation at the in-process potential, (c) material being present and (d) a propagating reaction occurring, (3) simultaneous events must be considered, and (4) how the use of simple ratios of in-process potentials and threshold initiation data can be misleading; e.g., cleaning the mixer was acceptable originally but when the overall probability is considered the risk of this operation becomes acceptable and the most hazardous of those analyzed.

The use of this risk analysis method is only as good as the engineering and statistical techniques used in obtaining the data. That is, the data employed in the analysis must be precise and accurate. Some of the problems encountered are:

(1) Establishing the process event probability with a high degree of confidence. The best method is direct observation using accepted work/sampling techniques. This method is not always possible which requires mock-up techniques under simulated environmental conditions. This ability to simulate the environmental conditions, e.g., working space, contamination, personnel habits, and procedures, are critical to obtaining accurate data.

(2) Accuracy of failure rate data for equipment - Data banks such as FARADA-ROME are generic in nature and do not represent a specific environmentel condition. The best historical data are usually derived from preventative maintenance records with equipment manufacturers being the least reliable source. Actual testing under environmental conditions, including stop-start conditions, provide accurate failure rate data but caution must be used in accelerated tests because of the aging or corrosion effects.

(3) Human behavior effects - This is a major variable and is not time dependent; e.g., the probability of a human making an error is 10^{-3} regardless of the number of times the operation has been performed. A higher probability of error can be expected during the initial learning period.

(4) Cost data - In general, industry has more accurate manufacturing and equipment cost information than government. In either case, the data are good if a process is in the production stage. At the pilot plant stage, it is generally acceptable and of questionable value at the concept stage.

TRADEOFF STUDIES

The risk analysis provides the basic data to generate tradeoff studies of risk vs cost or productivity. This phase of risk analysis is a subject in itself so only a simple example will be utilized to illustrate some of the benefits. The example is the pneumatic transport of solids through a pipeline which impinge on the conveying and receiving surfaces (Figure 12). The transfer velocity is 6000 fpm for a clean duct system. The threshold initiation velocity for the standsrd particulate distribution is 38,000 fpm with a probability of initiation of 10^{-11} at the in-process transfer velocity of 6000 fpm. The probability that the event (impingement) will occur, that contamination is present, and that a dust explosion will propagate if initiation occurs, is 1.0. The incident probability is 10^{-11} or:

$$E_p \bullet I_p \bullet C_p \bullet P_p = I_p$$
$$1.0 \bullet 10^{-11} \bullet 1.0 \bullet 1.0 = 10^{-11}$$

a low and acceptable probability for this operation. However, the problem of material building up in the pipelines with time must be considered because the larger particles (> mass) that can flake off and be transported through the lines reduce the threshold initiation values e.g., 12,000 fpm for a one-inch

cube. This, in turn, reduces the initiation probability to 10^{-2} resulting in an incident probability of 10^{-2}, again,

$$\begin{array}{ccccccccc} E_p & \cdot & I_p & \cdot & C_p & \cdot & R_p & = & I_p \\ 1.0 & \cdot & 10^{-2} & \cdot & 1.0 & \cdot & 1.0 & = & 10^{-2} \end{array}$$

This high probability is unacceptable because an explosion would result in losses in excess of \$1 x 10^6 dollars. Several of the design and operating alternatives available to alleviate the problem are moisture control of the intake air to minimize the material buildup, detection of pressure differentials to shut the system down, preventative maintenance to clean the system at a determined time (or thickness of buildup) or a non-pneumatic transport system.

All of the alternatives need to be studied but for illustrative purposes, the results of a preventative maintenance program is presented in Figure 13. This figure shows the effect of periodic cleaning of the conveying lines to prevent accumulation of the material. The plot is the buildup thickness accumulated vs expected cost with the corresponding change in risk. Normally, a plot of time versus varying thicknesses would be used. However in this feasibility study, the time was not known so the thickness which should not be exceeded was plotted. The expected cost is the product of incident probability times the cost due to an explosion, should the incident occur, plus the cost of maintenance. Maintenance coat, for this example, included production losses, or business interruptions, equipment parts, labor cost, etc. The plot shows the accumulation of material should not be allowed to exceed a thickness of 0.65-0.75 inch to provide the minimum risk; i.e., an incident probability of

10^{-4} to 10^{-6} with corresponding expected costs of \$6000 to \$8000. Less risk can be obtained by increasing the maintenance schedule to prevent thickness greater than 0.3 inch but at a threefold increase in cost. Other typical areas where risk analysis and tradeoff studies to varying degrees have been performed or are under way include over 30 projects in the Department of Defense and Industry, some of which are shown in Figure 14.

Some of the benefits of a quantitative hazard and risk analysis are:

(1) Experience with the process is not required to make decisions regarding the hazards associated with operations or equipment.

(2) Data are in terms which allow one to alter the process, procedures or the material within well-defined limits for reasons of safety, cost and productivity.

(3) Provides basic design and operating criteria useful to concept studies, pilot plant design and changes to existing processes. For example, one can

- -- Reduce operating velocities which increase the force necessary to initiate a material
- -- Reduce or limit the potential force by using materials of construction that yield before reaching the initiation force
- -- Maintain material below the dimensions critical for flame propagation or explosive reactions

(4) Provide the risk and loss potential as a function of time for either

-- Single compounds within a system, or

-- the entire system

(5) Allow totally different processes or configurations to be compared in terms of Item (4).

SUMMARY

In summary, risk analysis, when coupled with a quantitative hazard evaluation technique using engineering terms, allows one to optimize safety, cost and productivity through tradeoffs while maintaining quality at status quo. It also provides the risk, potential losses as a function of risk, and cost required to reduce these losses as a function of time. Risk analysis also yields the design and operating criteria to implement the decisions and recommendations derived in the tradeoff studies.

TABLE I
Quantitative Safety Margin

ONE-PINT SLURRY OPERATION	MODE OF INITIATION	IN-PROCESS POTENTIAL	TIL	SAFETY MARGIN
PLACING LID ON MIXER	IMPACT	840 ft/lbs/sec	1,680 ft-lbs/sec	2.0
CLEANING MIXER BOWL	FRICTION	3000 psi @ 1.0 fps	24,000 psi @ 1.0 fps	8.[illegible]
OPERATING VALVE (BOOT FAILS)	FRICTION	34,000 psi @ 1.0 fps	24,000 psi @ 1.0 fps	0.7

TABLE II
Frequency of Exposure Effect

AUTOMOTIVE	MILES TRAVELED	PROBABILITY
DEATH		
DAY	30	1×10^{-6}
MONTH	900	3.6×10^{-5}
YEAR	10,900	4.6×10^{-4}
LIFETIME (50 YEARS)	540,000	2.3×10^{-2}

TABLE III
Risk Analysis
(Probability)

PROPELLANT SLURRY OPERATION	ENGR. TERM	EVENT (E_p)	INITATION (I_p)	MATERIAL PRESENT (C_p)	PROPAGATION REACTION (R_p)	INCIDENT (I_p)	SAFETY MARGIN
PLACE LID ON MIXER	840 (ft·lb/sec)	10^{-2}	10^{-5}	10^{-3}	10^{-2}	10^{-12}	2.0
CLEANING MIXER	3000 (psi) @ 1.0 fps	1.0	10^{-3}	1.0	10^{-2}	10^{-5}	8.0
OPERATE VALVE (BOOT FAILS)	34,000 (psi) @ 1.0 fps	10^{-4}	1.0	1.0	10^{-2}	10^{-6}	0.7

TABLE IV
Exposure

PROPELLANT SLURRY OPERATION

	FREQUENCY PER DAY	MONTH	YEAR
● PLACING LID ON MIXER			
NUMBER	3	60	720
$I_p \cdot 10^{-12}$	10^{-12}	10^{-11}	10^{-10}
● CLEANING MIXER			
NUMBER	300	6000	72,000
$I_p \cdot 10^{-5}$	10^{-3}	10^{-2}	10^{-1}
● OPERATING VALVE			
NUMBER (Cycles)	---	3000	36,000
$I_p \cdot 10^{-6}$	10^{-6}	10^{-5}	10^{-4}

MATERIAL (DUST)	MINIMUM ENERGY (JOULES)
X	1.20
STD	0.80
Y	0.02

Figure 1. Qualitative Method

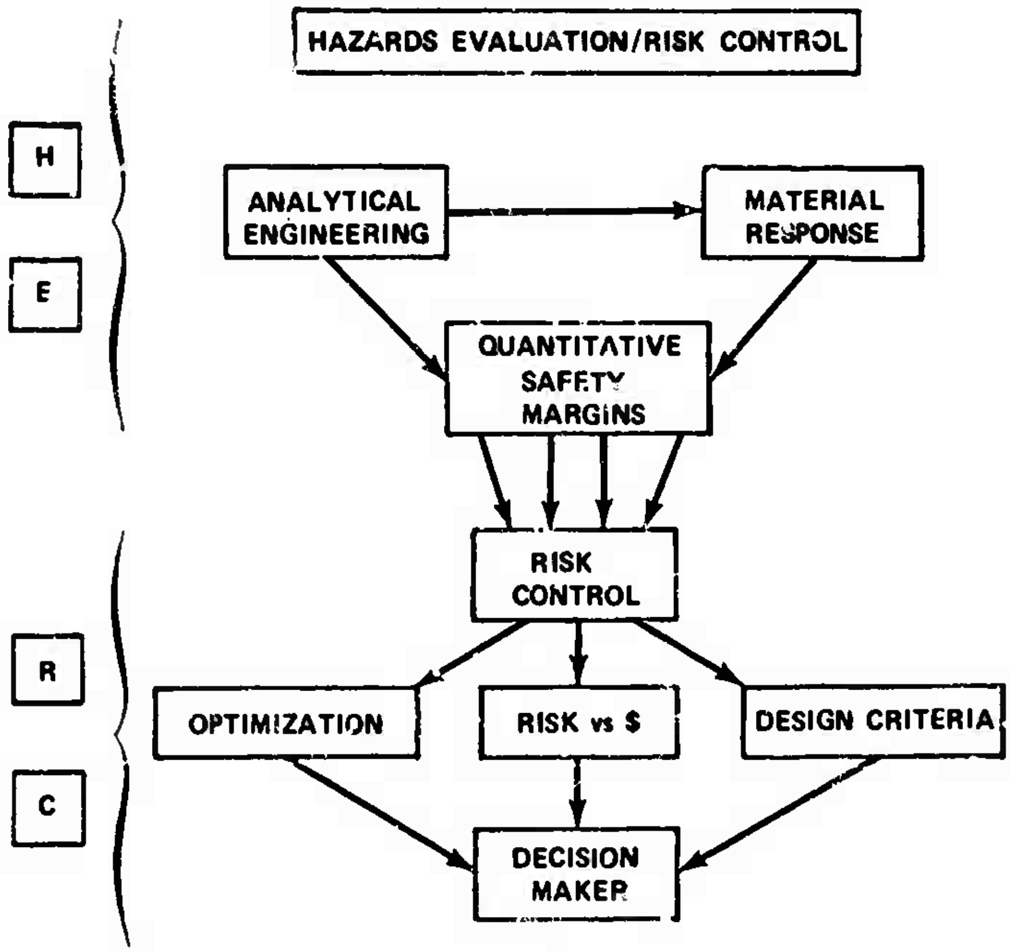

Figure 2

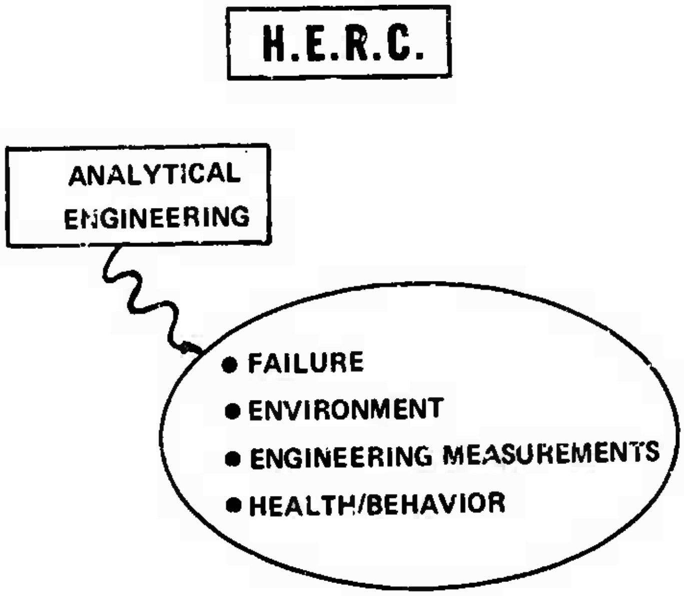

Figure 3

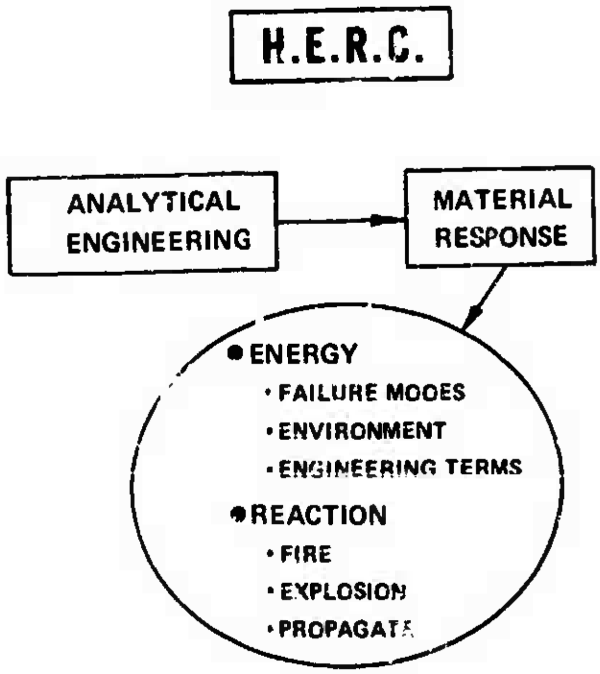

Figure 4

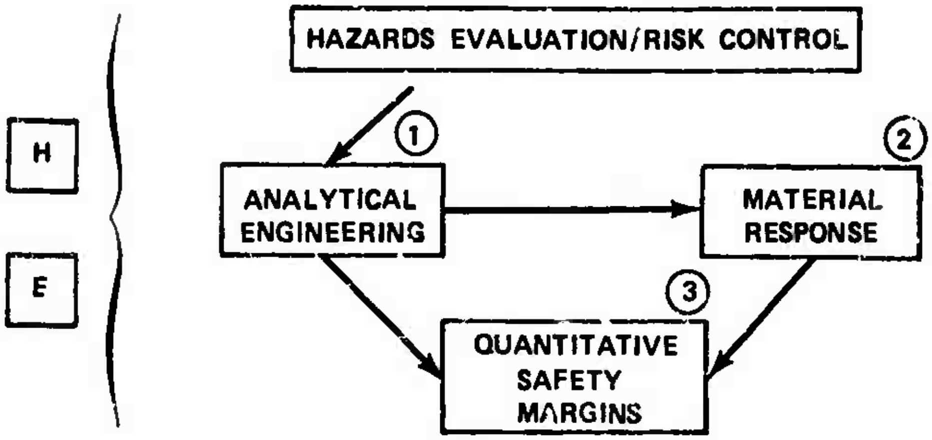

Figure 5

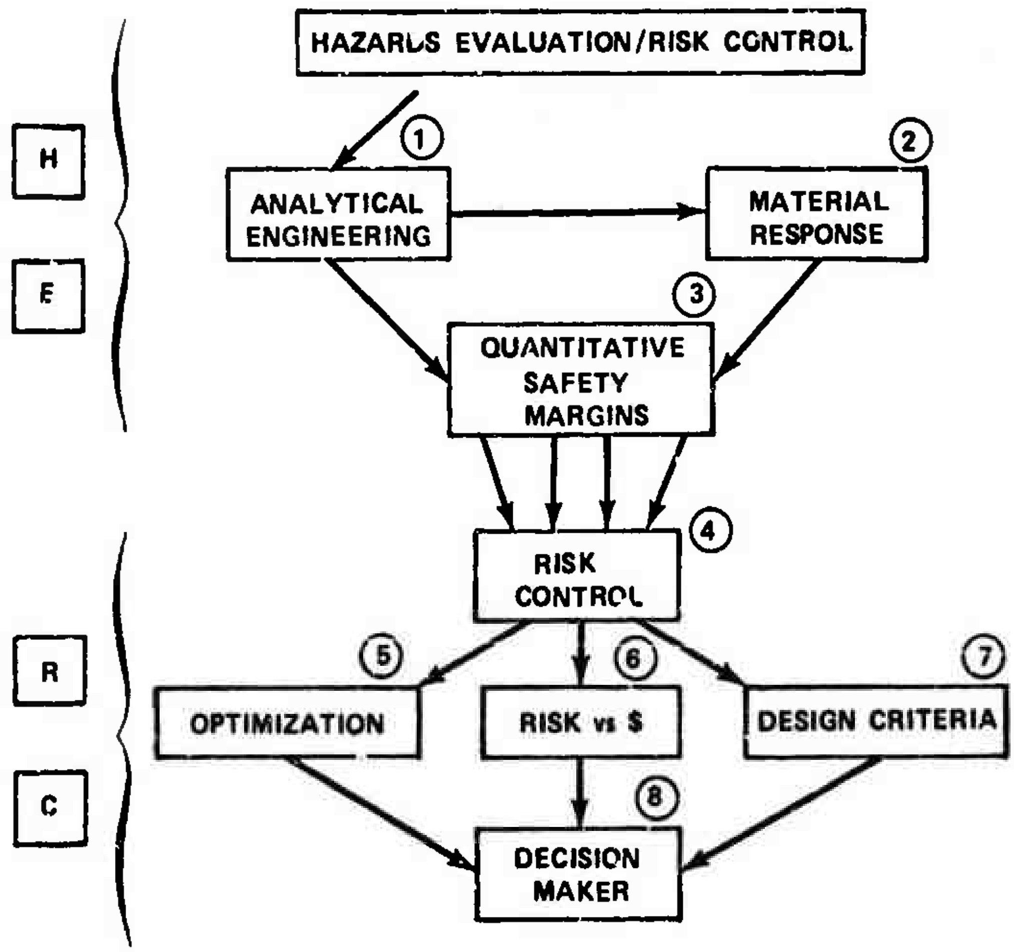

Figure 6

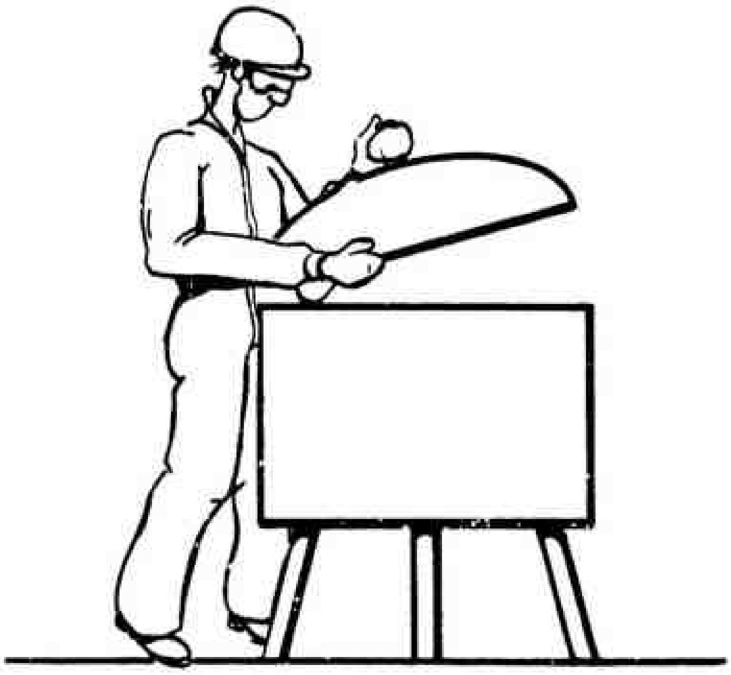

Figure 7. Lid Impacting Mixer

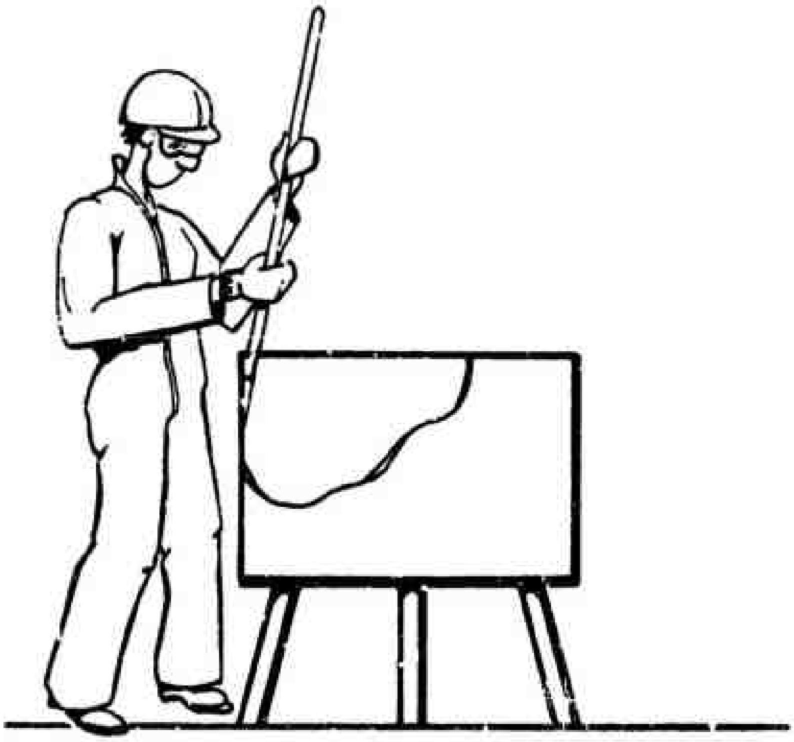

Figure 8. Cleaning Mixer

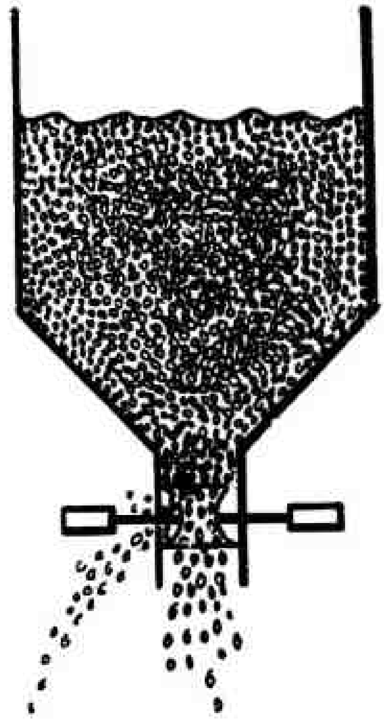

Figure 9. Valve Boot Failure

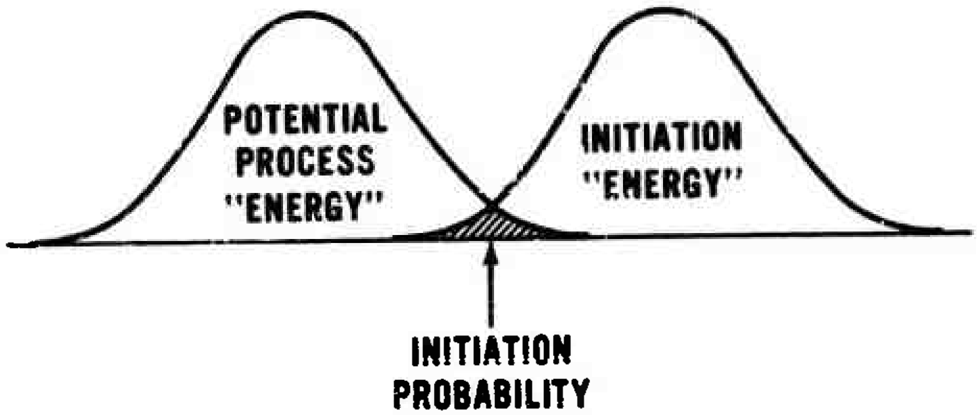

Figure 10. Probability of Initiation

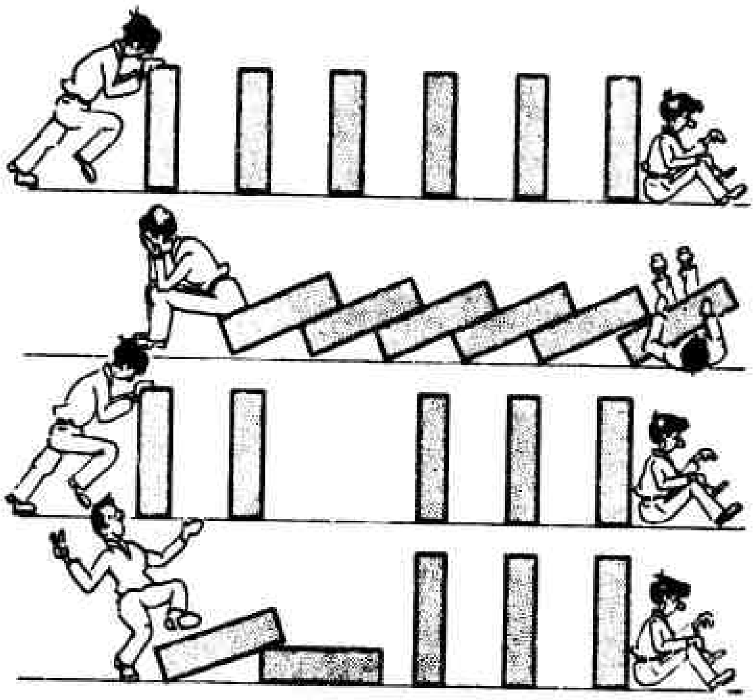

Figure 11. Simultaneous Events

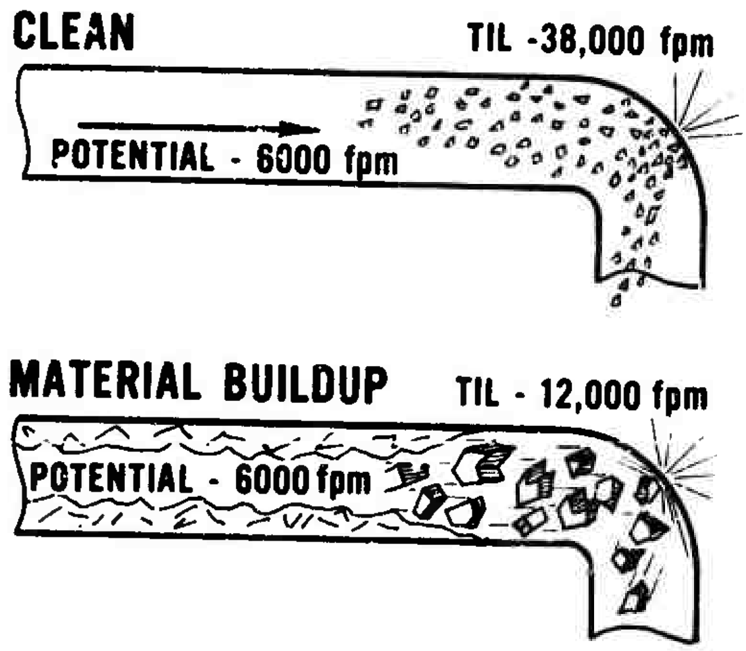

Figure 12. Pneumatic Transport

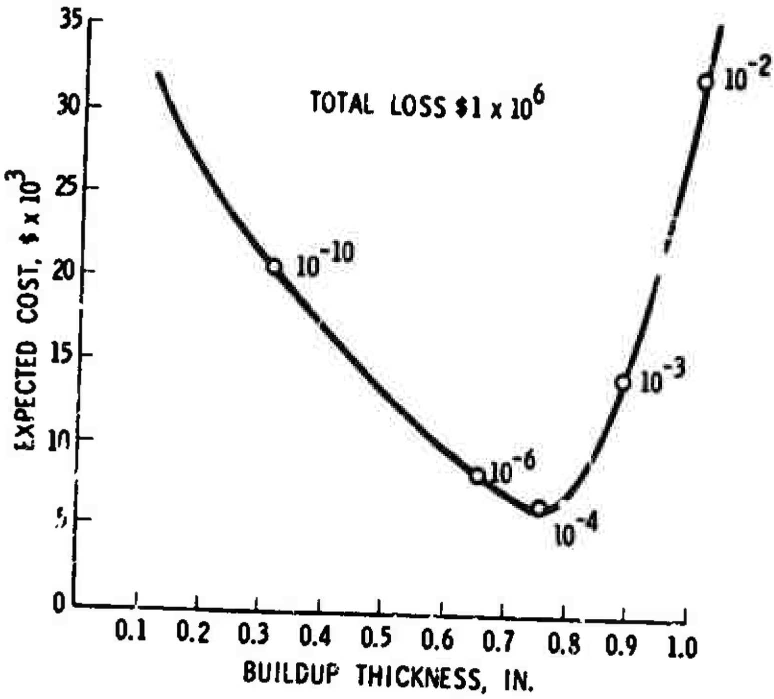

Figure 13. Cost/Maintenance Trade-Off

DOD (32)

- NITROGUANIDINE MANUFACTURE
- PRIMER/TRACER/DETONATOR LOADING
- MELT POUR PROCESS
- CONTINUOUS TNT/NC/PASTE
- AUTO SINGLE & MULTI BASE
- AUTO. ROLL POWDER
- PNEUMATIC TRANSPORT (TNT/COMP-B)
- AMMONIA OXIDATION PLT.
- NAVY MODERNIZATION STUDY

INDUSTRY

- MATERIAL HANDLING (PE, TPA, PET)
- POLYPROPYLENE MANUFACTURE
- TEXTILES FLAKE DOPE – YARN
- DYE MANUFACTURE

Figure 14. Risk Analysis 1972

SWEETIE BARREL CHUTE HAZARDS ANALYSIS

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ABSTRACT

In-process gun propellant moisture content was increased to reduce hazard and costs of coating operations. This required that the loading chute slant angle be increased to prevent hang up of wet powder as it poured into a sweetie glaze barrel. To assess the potential hazards due to this change, IIT Research Institute utilized a failure mode and effects analysis of the overall loading operation. As a result, a number of sensitivity tests were devised and conducted to determine the likelihood of initiation due to energy stimuli levels expected in the system. As a highlight to the study, a systematic electrostatic charging analysis for powder flow in any system was conducted. To form this, detailed experiments were conducted on powders and the physical hardware to determine. electrostatic buildup at critical points and ESD initiation sensitivity of powders. Based on the hazards analysis and tests, recommendations were established to maximize safety of the operation.

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CONTENTS

ACKNOWLEDGMENTS

The success of the Hazards Analysis presented herein was attributed to the excellent working relationships established between IIT Research Institute and Olin Energy Systems Division personnel. Special appreciation is extended to George Shalabi, Olin Energy Systems, for his fine contributions of mechanical sensitivity testing and system electrostatic measurements. Mr. Ray Zalewski, IIT Research Institute was invaluable in electrostatic sensitivity characterization of the powders and for electrostatic analysis on the system. The authors would like also to extend appreciation to Hyla Napadensky, IIT Research Institute for her safety analysis guidance to the safety analysis program.

November, 1972

SWEETIE BARREL CHUTE HAZARD ANALYSIS

1. INTRODUCTION

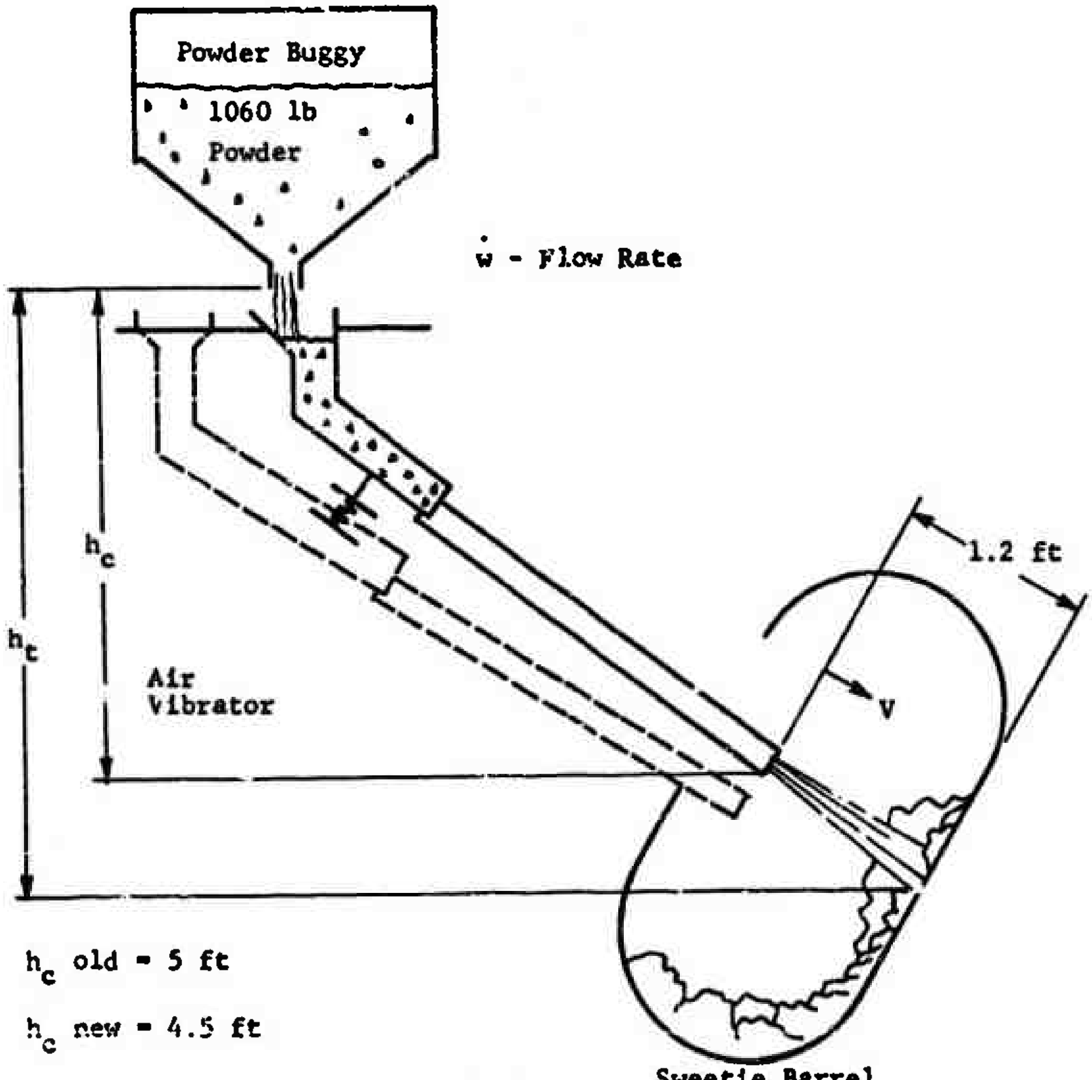
On 14 February 1972, IIT Research Institute (IITRI) was requested by Olin Energy Systems Division, Badger AAP to conduct a hazards analysis on a modification to a loading chute for the Sweetie Barrel loading operation.

Olin has contemplated removing tray dryers in the Ball Powder coating line so that drying of propellant would be performed in a Sweetie Barrel during propellant salt coat or glaze operation. In evaluating the effect of pouring water wet (20-25 percent by weight) Ball Powder, from the powder buggies to the Sweetie Barrel, significant problems arose relative to maintaining rapid material transfer. The wet Ball Powder tended to bridge on the existing chute thus slowing down the Sweetie Barrel loading cycle significantly. Olin engineering staff proposed changing the angle of incline of the present chute to a steeper one and adding an air driven vibrator to the chute to allow the wet Ball Powder to flow more freely into the Sweetie Barrel.

The purpose of the IITRI conducted hazards identification and analysis was that of defining if any change in safety of operation would occur due to this modification.

2. SYSTEM DESCRIPTION

In the present operation, the "circle" powder buggy containing approximately 1060 lbs of uncoated Ball Powder in its dry form is rolled over the existing chute as shown in Figure 2.1. The operator connects the ground strap from the powder buggy to the permanent copper chute and then opens the buggy door to allow the



h_c old = 5 ft

h_c new = 4.5 ft

V ~ Powder Velocity at end of chute

$\dot{w}$ old = 5.9 lb/sec

$\dot{w}$ new = unknown

Figure 2.1 SWEETIE BARREL CHUTE ARRANGEMENT

Ball Powder to flow into the chute. A five foot length of open chute (conductive rubber) directs the powder flow into the barrel. The geometry of the existing chute arrangement is also shown in Figure 2.1. At present, the dry Ball Powder flows very uniformly through the chute and into the Sweetie Barrel at a flow rate of 530 lbs per minute (~ 10 feet per sec). Once the powder is drained from the powder buggy, the operator, utilizing a cloth covered broom, sweeps the powder hung in the chute out in the Sweetie Barrel. The portable five foot chute length is then removed and the operation prepared for the next step.

The proposed modifications to this chute configuration is also shown in Figure 2.1. The permanent chute has a higher angle of incline (~45°) and also incorporates an air vibrator to facilitate muvement of wet Ball Powder through the chute. To accommodate higher chute angle, the powder buggy had to be moved closer to the end of the structure as shown in Figure 2.1. In the proposed system, the flow head for the Ball Powder from the powder buggy to the Sweetie Barrel would be reduced by approximately 1/2 feet.

3. HAZARDS IDENTIFICATION AND ANALYSIS

The hazards analysis conducted by IITRI consisted of identifying potential hazards and material sensitivities relative to the specific operation. Hazards analysis tests were conducted by Olin Energy Systems to support the IITRI analysis. In the proceeding paragraphs, discussions of hazardous environments, material sensitivity and hazards identification are reported.

3.1 Hazardous Environments

A great potential in the operation exists for developing of electrostatic charge in the powder due to flowing of the powder in the chute. In addition, any dusting which would occur in the

Sweetie Barrel when the powder impacts could be initiated by electrostatic discharge. Also, in the case of salt coating, powder solvent (isopropyl alcohol) vapors could be initiated by any undue electrostatic charge buildup. A second primary hazardous environment associated with this operation is that of the impact of the uncoated Ball Powder onto the Sweetie Barrel at high velocities. Extraneous environments such as heat, mechanical sparking, etc. must also be considered. When wet Ball Powder is poured into the Sweetie Barrel, electrostatic buildup would be considered less severe since frictional or triboelectrical static charge buildup in crystals and powder can be reduced in the presence of water. Also, the increase in moisture content of the powder would greatly reduce the dusting which can occur in the present system. However, the addition of water can produce several adverse effects. First, the water carrier in the powder would increase the possibility of forming thin coatings of powder on the chute during the pouring operation. The coatings can act as insulators between the chute and the powder to essentially reduce the static electricity drain-off from the powder. This could result in increases in static voltage buildup in the powder during the pouring operation. The second possibility is that if water content is high, a static electric charge can build up between segments of the powder which is not uniformly linked with the water to develop even further increases in static electricity. Essentially any time two materials with different dielectric constants under a frictional or triboelectrical type of flow can develop larger electrostatic charges than when both materials have the same dielectric constant.

An illustration of charge buildups in the typical solid feed system is shown in Figure 3.1. Also, in this figure the charge concentration for various types of material flow is shown. Some

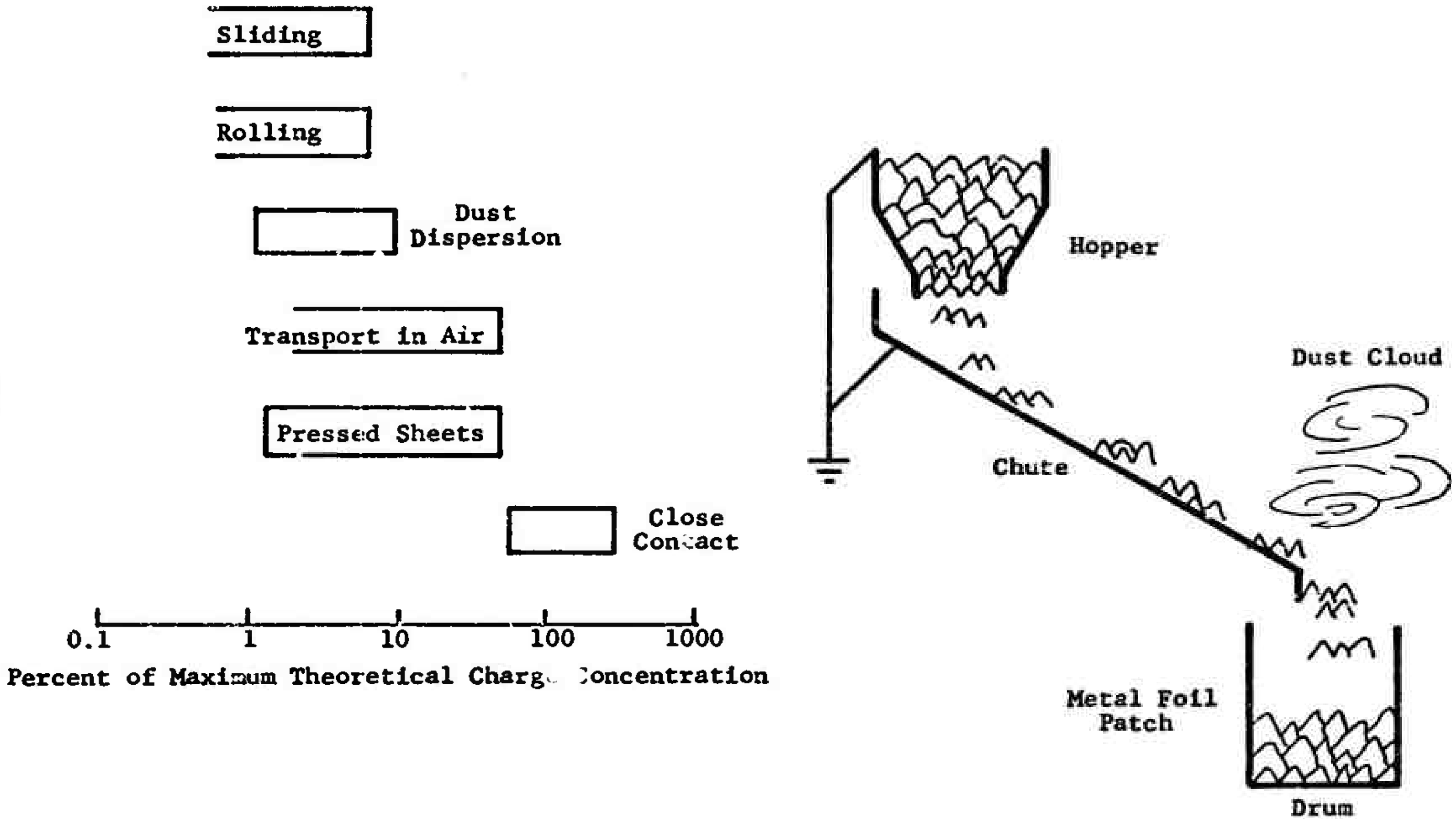


Figure 3.1 TYPICAL STATIC ELECTRICITY CONDITIONS FOR POWDER UNLOADING

Ref. Static Electricity Hazards, D. Saletan, June 29, 1959, Chem. Eng.

examples of the minimum initiation energy required for various fuel air mixtures and concentrations as related to effective particle sizes is shown in Figure 3.2.

From a mechanical standpoint, the impact sensitivity of the uncoated Ball Powder must be thoroughly assessed relative to effect of adding water to the material. Actually, the powder impact with the Sweetie Barrel can create two types of problems. The impact itself could be suffcient to cause initiation of the powder providing that the powder impact energies are high. Also, particle impingements due to the oncoming stream into the Sweetie Barrel could cause initiation possibilities.

3.2 Material Sensitivity

A list of sensitivity thresholds for the subject Ball Powder and three additional references (NG, NC and N-5 propellant paste) are listed in Table I. From the electrostatic discharge analysis standpoint, insufficient information was available to accurately define the material sensitivity due to static electricity discharge. At the beginning of the program, IIT Research Institute staff members conducted detailed electrostatic characterization tests on Ball Powder plus several reference materials. Results of these tests are shown in Table II. In addition, impact sensitivity tests were conducted on wet and dry Ball Powder at Olin using a drop test fixture. A significant increase in impact sensitivity was noted from Olin tests when 20-25 percent water was added to the driest powder.

3.3 Hazards Identification

Each step of the operation from the time that the powder buggy is moved over the chute to the final fill of the Sweetie Barrel was explored to determine potential hazards which could occur at each step in the process. First, potential failures

TABLE I

MATERIAL SENSITIVITY DATA

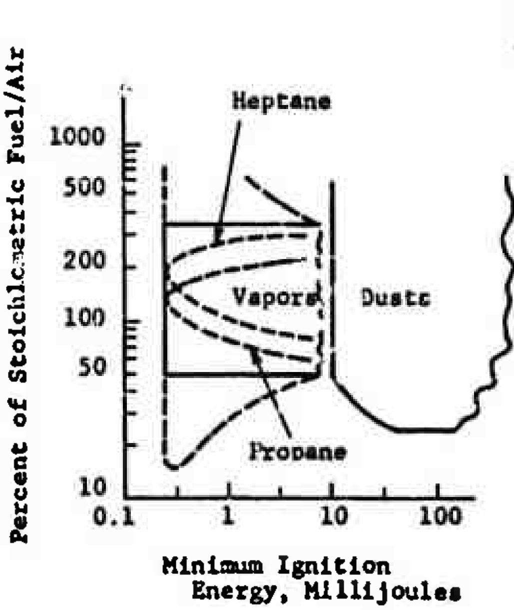
Data Point	Salt Coated & Glazed Ball Powder	20-25% Wet Ball Powder	Dry Ball Powder	Referenced Material: Nitrocellulose	Referenced Material: N-5 Paste
BU Mines 2KG WT Impact Test 50% (cm)	-	**16	**31	8	[illegible] Dry 18 Wet 10%
Electrostatic Discharge Initiation Energy (Joules)*	4.5	**7.5	[illegible].5	.125	.075 10% Wet or Dry
Dielectric Strength	Unknown	Unknown	Unknown	280-400 Volt/Mil	
Dielectric Constant	Could Not Be Measured	Unknown	1.8	6	
Volume Resistivity (ohm-cm)	[illegible]	4.42×10^{7}	1.35×10^{13}	1.6×10^{11}	2.27×10^{10}
Bulk Conductivity (mho/cm)	3×10^{-2}	2.26×10^{-8}	7×10^{-14}	6.19×10^{-12}	Wet 1520×10^{-12} 0.513×10^{-12} Dry

* 10^{7} ergs
** Olin Tests

TABLE II

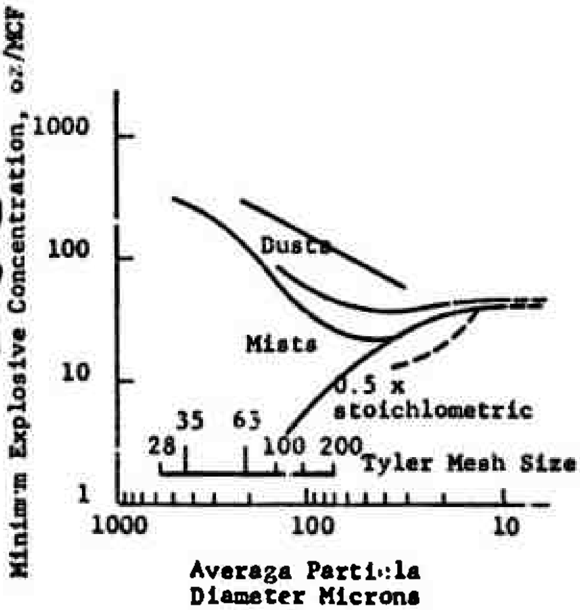
SWEETIE BARREL HAZARD ANALYSIS ESD TEST RESULTS

Material	Capacitor	Energy In Spark	Result	Spark Resistance	Bulk Conductivity	Bulk Resistivity	Dielectric Constant
Pure NC	8.00 Joules	4.6 Joules	Go	0.55	6.19×10^{-12} /cm	1.62×10^{11}cm	
Pure NC	2.00	1.35	Go	0.87			
Pure Nc	0.50	-	No Go	-			6.0
Pure NC	0.50	0.34	Go	0.87			
Pure NC	0.125	-	No Go	-			
Pure NC	0.125	-	No Go	-			
Pure NC	0.18	0.0104	Go	0.55			
Pure NC	0.32	0.114	Go	0.23			
N-5 Paste	0.50	0.40	No Go	1.5	4.41×10^{-11}	2.27×10^{10}	
N-5 Paste	2.00	0.78	No Go	0.26			
N-5 Paste	2.00	0.78	No Go	0.26			?
N-5 Paste	8.00	4.5	Go	0.66			
N-5 Paste	7.22	4.1	Go	0.66			
N-5 Paste	4.50	3.2	-	0.16			
Regular Dey	6.00	4.0	No Go	0.41	7.42×10^{-14}	1.35×10^{13}	
Ball	18.00	5.1	Go	0.16			1.8
Powder	32.00	4.5	Go	0.07			
Straw	18.00	5.1	No Go	0.16			
Powder	32.00	4.5	Go	0.07	-	-	?
	32.00	4.5	Go	0.07			
Ball	8.00	2.3	No Go	0.16	6.88×10^{-5}	1.45×10^{4}	
Powder	18.00	5.1	Go	0.16			?
(2)	32.00	4.5	Go	0.07			
	50.00	5.3	Go	0.05			
Wet Ball Powder (1)	-	-	-	-	2.26×10^{-8}	4.42×10^{7}	?
Unglazed Ball Powder	-	>5	No Go	-	4.75×10^{-15}	2.1×10^{14}	2.0
Salt Coated and Glazed Ball Powder	-	>5	No Go	-	3.37×10^{-4}	2.95×10^{3}	?
Glazed Only Ball Powder	-	>5	No Go	-	1.35×10^{-3}	7.4×10^{2}	?



Regions where Fuel Air Mixtures Explode

Dusts belong in the same explosive picture as vapors. The above Figure shows the hazardous region for both in terms of explosive concentration limits, and minimum ignition energies. The square region embracing the curves for heptane and propane is the hazardous area for these two vapors. Other materials show wider limits (dotted lines outside).



Consider Particle Size Effect

Particle size can greatly effect the minimum explosive concentration of dusts and mists. Very fine particles (less than 50 microns) behave like vapor fuels. With increasing mists droplet size, the lower limit drops due to a sedimentation effect. Dusts show no such effect; minimum explosive concentration decreases with decreasing particle size.

Figure 3.2 INITIATION ENERGY AND PARTICLE SIZE EFFECTS

Ref. Static Electricity Hazards, D. Saletan, 1 June 1959, Chem. Engineering

were identified for each of the process steps. Then the potential hazard arising from that hazard was described. The hazard classifications were divided into the following categories:

Class 1 - Potential personnel injury or equipment damage of a minor nature.

Class 2 - Personnel injury or equipment damage of major level with no catastrophic effects.

Class 3 - A potential fire hazard with major injury to personnel.

Class 4 - Major fire or explosive hazard with catastrophic effects.

From each of the process failure potentials, means of eliminating the hazard or failure were described in this study and a resultant hazard classification consequently assigned.

4. SENSITIVITY ANALYSIS

The ability to evaluate system safety depends on first being able to identify all credible hazardous areas. Once hazard areas are identified, sensitivity analysis can be performed. Basically, sensitivity analysis consists of analytically or experimentally evaluating the initiation sensitivity of a reactive material to expected environmental stimuli.

In the Sweetie Barrel loading operation, the uncoated Ball Powder was considered as the reactive material. Chemical and physical characteristics of the powder are illustrated in Table IV. During the salt coating operations in the Sweetie Barrel vapors of coating solvent (isopropyl alcohol) can exist in the loading area. This material presents a vapor cloud initiation sensitivity hazard if sparking should occur in the area. Chemical,

TABLE IV

BALL POWDER PROPERTIES

Type Powder:	WC 844 Series
Web Size:	~0.015 inch
Gravimetric Density g/cc:	= 0.98
Percent Nitroglycerin:	10.2
Percent Dibutylphthalate:	3.75-4.25
Percent Nitrocellulose:	~85
(Nominal nitrogen content of nitrocellulose = 13.15%)	
Autoignition Temperature (°C):	200
Heat of Explosion (Cal/gm):	886

SALT COAT SOLUTION ADDED

Isopropanol
Dibutylphthalate
Ethyl Cellulose
Potassium Nitrate
Tin Dioxide

GLAZE MATERIAL

Graphite

physical and sensitivity characteristics of isopropyl alcohol are listed in Table V. As a result of changing the coat and glaze operations by utilizing wet Ball Powder, a change in Ball Powder sensitivity characteristics is expected although no significant change in powder environments will occur.

The operational environments which could produce energies sufficient to initiate the above mentioned reactive materials are listed as follows:

- mechanical pinching loads
- mechanical impact loads
- material impingement loads
- friction loads
- electrostatic charge buildups
- chemical reaction mechanisms
- electrical sparking

Of these environments, the mechanical impact loads and electrostatic charge buildups pose the greatest threat to powder and solvent vapor initiation. The other environments do not appear to generate energies of any significant magnitude. Detailed sensitivity analysis on impact and electrostatic environments are discussed in the following paragraphs.

4.1 System Electrostatic Analysis

When Ball Powder flows from the powder buggy to the chute, electrostatic charge develops in the powder due to powder flow through the buggy mouth. Also, as the powder flows down the chute, additional electrostatic charge is developed on the powder. When the powder reaches the Sweetie Barrel, it will begin to store electrostatic energy, based on the degree of charge bleedoff afforded by the equipment grounding and the powder resistance. The electrostatic charging phenomenon is

TABLE V

ISOPROPYL ALCOHOL PROPERTIES

1.	Melting point:	-89°C
2.	Boiling point:	82.4°C
3.	Latent heat of vaporization (at boiling point):	9729 $\frac{\text{Cal}}{\text{g mole}}$
4.	Liquid density:	0.784 gm/cc
5.	Gas density:	0.00208 gm/cc
	One atmosphere and 97°C:	2.07 that of air
6.	Autoignition temperature in air:	750°F
7.	Lower explosion limit in air:	2.6% (v/v_{air})
8.	Upper explosion limit in air:	12% (v/v_{air})
9.	Flash point:	53°F
10.	Vapor pressure	33 mm @ 20°C
11.	*Electrostatic sensitivity 8% by volume in air:	0.2 millijoules

*Union Carbide supplied data.

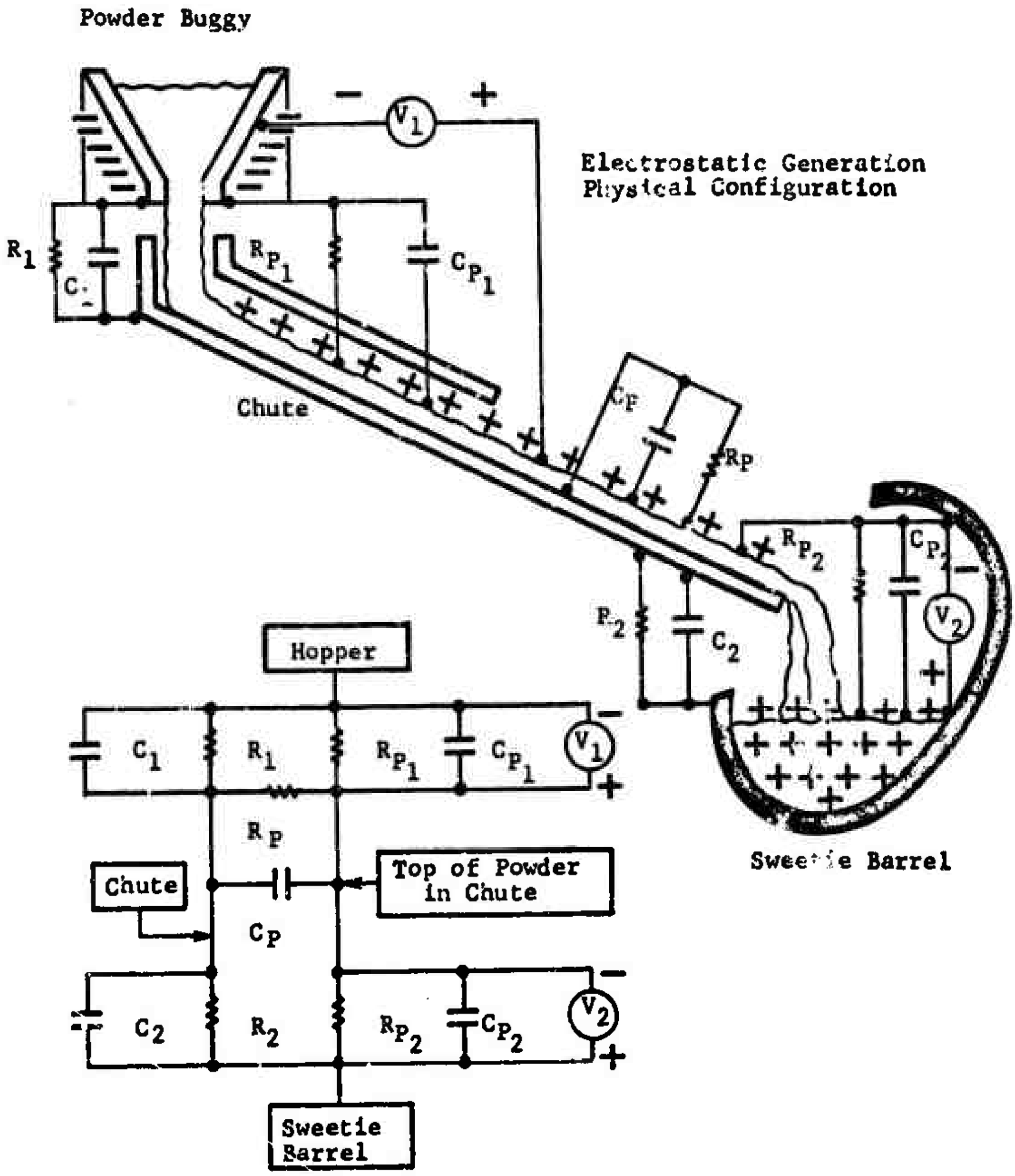
illustrated in Figure 4.1. From an electrical standpoint, an electrostatic generation and storage model was formulated for the Sweetie Barrel chute operation. Using this model, we can establish the electrostatic buildup capabilities of the system as based on powder and equipment characteristics. This model is also shown in Figure 4.1.

In the electrical model, we would like to have all resistances to ground and between equipment to be nearly zero. This is not always true in a plant operation. If grounding is lost on a piece of equipment (e.g. as between the chute and the Sweetie Barrel), a significant electrostatic charge can be stored on the chute. Also, if the powder internal resistance and capacitance is high, the grounding may not help much is dissipating the static electric charge generated in powder flow.

If we consider the worst case situation, the resistance and capacitance equivalents to ground (e.g. R_1, R_2, C_1 and C_2) would all be dropped from the circuit. In addition, we can consider a worst case situation where the powder resistance and capacitance between the chute and Sweetie Barrel/powder buggy would be greater than that between powder and chute. Based on this model simplification the following electrostatic characteristics were analyzed.

4.1.1 Powder Buggy Electrostatic Charging

Since the flow path was short and powder flow very slow in the buggy, electrostatic charge generation was considered to be much less than that for flow in the chute. Thus no analysis was conducted in this area. We considered that at most its electrostatic energy developed would be less than one half of that in the chute.



Electrostatic Generation Electrical Model

Figure 4.1 ELECTROSTATIC CHARGING MODEL ILLUSTRATION

4.1.2 Electrostatic Charge Buildups in Chute

For the powder in the chute, the following calculations of powder electrostatic buildup and drainoff are shown:

Powder Resistance

Resistance $R = \frac{L}{\sigma A}$

where

L is thickness of powder in chute

A is surface area of powder in chute

σ is bulk conductivity.

For the powder

$A = l \times w$ = length x width of powder in chute

Assuming

$W = 6$ in.

$L = 84$ in.

$A = 505 \text{ in.}^2 = 3250 \text{ cm}^2$

$L = 1 \text{ in.} = 2.54 \text{ cm}$

Therefore resistance for the wet powder is:

$\sigma = 2.26 \times 10^{-8}$ MHO/cm

$R_{wet} = 3.46 \times 10^{4}$ OHM

For dry powder:

$\sigma = 7.42 \times 10^{-14}$ MHO/cm

$R_{dry} = 1.05 \times 10^{10}$ OHM

Powder Capacitance:

Capacitance of powder on chute was calculated using the following equations:

$C = 0.088\ KA/_t$

where

K ~ dielectric constant of Ball Powder

A ~ surface area of powder = (l) length of chute x powder surface width (W_p) - cm^2

t ~ powder thickness - cm

For the chute, we assumed powder is on full run of chute and:

$t \cong 1.0$ inch

L = length of chute = 84 in.

W_p = powder width in chute ≅ 6 in.

$A \approx 505\ in.^2 = 3250\ cm^2$

and we measured

$K = 1.83$

Then powder capacitance was calculated to be

$C = 206\ \mu\mu f$

Powder Time Constant

The RC constant assuming powder capacitance in chute to be 206 μμf.

For dry powder:

$$RC_{dry} = 206 \times 10^{-12} \text{ Farad} \times 1.05 \times 10^{10}$$

$$RC_{dry} = 2.16 \text{ sec}$$

For wet powder

$$RC_{wet} = 206 \times 10^{-12} \text{ Farad} \times 3.46 \times 10^{4}$$

$$RC_{wet} = 7.15 \times 10^{-6} \text{ sec}$$

It is readily seen that the water wet powder will drain its charge very rapidly depending on moisture content. Although IIT Research Institute measurements of wet powder resistivity was low, no exact moisture content was observed. Thus, if water wet powder should dry out, its decay constant could increase significantly and cause an increase in electrostatic sensitivity.

Potential Voltage Buildup in Powder

The theoretical voltage buildup in the powder on the chute can be found from the calculations of powder capacitance and charge buildup. We now need only to calculate a theoretical charge density (Q) of powder during flow in the chute. Based on accepted values of electrostatic charge densities illustrated in reference 4.1 and Figure 3.1, up to 8% of theoretical maximum charge density would be expected due to powder sliding or rolling down the chute. Theoretical maximum charge density of 2.65×10^{-9} coulomb/cm^2 of surface is possible. Above this value, corona discharge occurs. Thus in our system a charge density as follows is expected:

$$\frac{Q}{cm^2 \text{ chute}} = 2.12 \times 10^{-10} \text{ coulomb/cm}^2$$

Ref. 4.1 "Electrostatics," by F. G. Eichel, March 13, 1967, Chemical Engineering Magazine.

Thus for a total powder surface area in the chute previously estimated to be $A = 505 \text{ in.}^2 = 3250 \text{ cm}^2$ the charge developed is:

$$Q = 6.9 \times 10^{-7} \text{ coulomb}$$

Then voltage potential can be calculated as follows:

$$\text{Voltage (V)} = \frac{Q}{C}$$

For the powder maximum voltage is:

$$V_1 = 3350 \text{ volts}$$

Electrostatic Energy Developed

Based on the potential in the powder, the electrostatic energy available in the powder on the chute at any one time can be found by the following equation:

$$J = 1/2 \ CV^2$$

where

J = energy stored in capacitor in joules

C = powder capacitance in Farad

V = powder potential-volts

Thus for the above powder conditions, the electrostatic energy expected in the powder is:

$$J_p = 0.5 \ (206 \times 10^{-12} \text{ Farad}) \ (3.35 \times 10^3 \text{ volts})^2$$

$$J_p = 11.6 \times 10^{-4} \text{ joules}$$

or

$$J_p = 1.16 \text{ millijoules}$$

If powder electrostatic charging were up to 90% of theoretical maximum, the electrostatic energy would increase significantly to values which could be hazardous as follows:

$$Q_{90} = 7.75 \times 10^{-6} \text{ coulombs}$$

and voltage would be

$$V_{90} = Q/c = 37{,}500 \text{ volts}$$

then electrostatic energy would be

$$J_{90} = 1/2\ cv^2 \text{ where } c = 200\ \mu\mu f$$

$$J_{90} = 0.144 \text{ joules}$$

or

$$J_{90} = 144 \text{ millijoules}$$

4.1.3 Electrostatic Charge Generation in Sweetie Barrel

A crude powder resistance value in the Sweetie Barrel was calculated based on a full barrel condition as worst case. Thus:

Resistance

Resistance $R = \frac{L}{\sigma A}$

where in this case we assume:

$L = 12$ in.

A = surface area of powder in barrel based on circle plate 36 in. diameter (1020 in.^{2})

Thus for wet Ball Powder:

$$\sigma = 2.26 \times 10^{-8} \text{ MHO/cm}$$

Then

$$R_{wet} = 2.05 \times 10^5 \text{ OHM}$$

For dry powder

$$\sigma = 7 \times 10^{-14} \text{ MHO/cm}$$

and

$$R_{dry} = 6.65 \times 10^{10} \text{ OHM}$$

Capacitance

Based on the standard capacitance equation, a crude powder capacitance was calculated as follows:

$$C = 0.088 \frac{KA}{t} \mu\mu f$$

where

K - dielectric constant = 1.83

A - powder surface area = 1020 in.^{2}

t - powder average thickness = 12 in.

then

$$C = 34.9 \mu\mu f$$

Powder Time Constant

In the RC time constant for powder is calculated as:

Dry Powder

$$t_c = RC = (6.65 \times 10^{11})(34.9 \times 10^{-12} \text{Farad})$$

$$t_{c_{dry}} = 23.20 \text{ seconds}$$

and for wet powder

$$t_{c_{wet}} = 7.16 \times 10^{-5} \text{ seconds}$$

We see here a much longer time interval required to dissipate the electrostatic charge in the barrel than in the chute.

Charge Buildup in Tumbling

If we consider maximum charge buildup due to barrel tumbling we get following charge and voltage buildups.

Assume

$$\frac{Q}{cm} = 80\% \text{ theoretical} = 2.12 \times 10^{-9} \frac{\text{coulomb}}{\text{cm}^2}$$

then for $A = 6550 \text{ cm}^2$

$$Q_{barrel} = 1.39 \times 10^{-5} \text{ coulomb}$$

and voltage buildup theoretically would be

$$V = \frac{Q}{C}$$

where $C = 34.9$ μμf then

$$V = 3.99 \times 10^5 \text{ volts}$$

Theoretical Electrostatic Energy Generated

The electrostatic energy can be found in the Sweetie Barrel as follows:

$$J = 1/2\, CV^2$$

where

C ~ powder capacitance ≅ 34.9 μμf

V ~ voltage ≅ 399 kv

then

$$J_{barrel} = 2.76 \text{ joules}$$

This is based on a very crude calculation of powder capacitance. This energy would be expected to be available at any time during the barrel tumbling operations. We notice that this energy value is very close to the initiation threshold of dry Ball Powder as shown in Table I. Actually, the value is assumed if no electrostatic charge can drain off the Sweetie Barrel and that there is no reversal of charge polarity during tumbling.

4.2 Powder Electrostatic Test Results

4.2.1 Test Descriptions

In the following paragraphs, each electrostatic test configured to evaluate powder charging characteristics is described.

Conductivity and Dielectric Constant

The conductivity of the various powder test samples was determined by placing the samples in a teflon tube between two metal electrodes. The total resistance between the electrodes was then measured and the conductivity determined from this measurement and the measurement of the length and cross section area of the sample.

Two concentric metal cylinders were used to measure the dielectric constant of the powder samples. The concentric cylinders structure was long compared to its diameter, and a teflon plug was inserted slightly into one end. The capacitance of this structure was then measured with air and then with the sample powder between the two concentric cylinders. The dielectric constant was then given to a good approximation, by the ratio of the two measured capacity values.

Electrostatic Discharge Tests

The energy required to ignite the various power samples tested was determined by discharging a charged capacitor into a sample of the power. The sample to be tested was placed in a plastic tube between two metal electrodes, see Figure 4.2. The capacitor was connected in series with the sample in the tube through a mechanically activated switch and a high power 0.05Ω resistor. When the capacitor was charged (through a circuit not shown in Figure 4.2) to the proper voltage, the mechanically activated switch would be closed and the energy stored in the capacitor would be discharged into the test sample, the series 0.05Ω resistor, and the internal resistance of the capacitor. To measure the energy supplied to the test sample the time histories of the voltage across the sample, and the current through the sample, were determined from oscilloscope pictures. Referring to Figure 4.2, an oscilloscope picture of the voltage, V_i, across the 0.05Ω resistor was obtained for each capacitor firing. The voltage scale of the picture thus obtained was then divided by the resistance, 0.05Ω, to give a time history of the current through the sample. Simultaneously with the measurement of V_i, an oscilloscope picture of the voltage, V, from the ground to the upper lead of the test sample was taken. The time history of the voltage across the sample could then be obtained from the expression:

$$V_{sample}(t) = V(t) - V_i(t)$$

Using values picked off these two oscilloscope pictures the energy into the sample could be determined from the integral.

$$J = \int_{t=0}^{t=\infty} iV dt = \int_{t=0}^{t=\infty} \frac{V_i}{0.05} (V - V_i)\, dt \qquad (1)$$

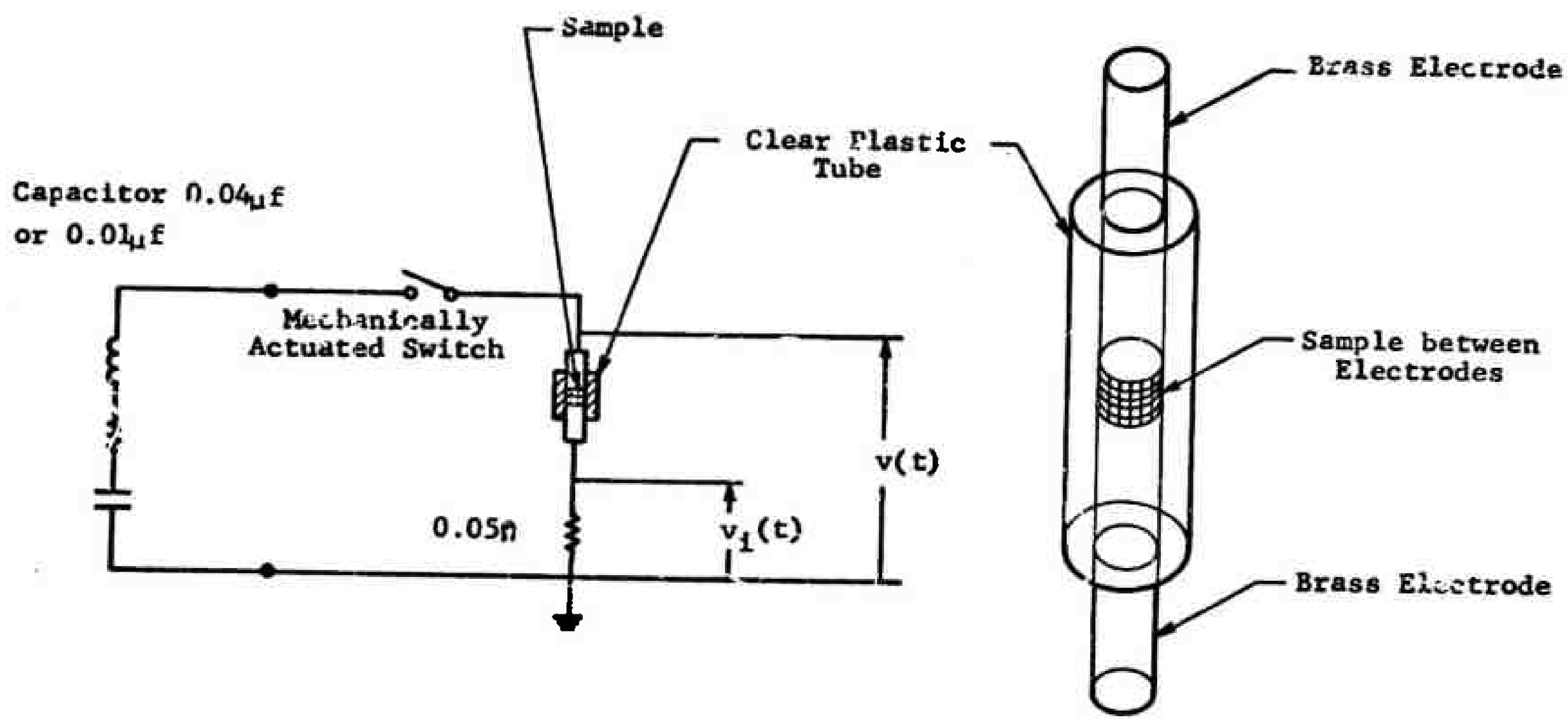


Figure 4.2 ELECTROSTATIC DISCHARGE TEST SETUP

During the tests on the samples the voltage to which tha capacitor was charged was increased in steps of a factor of two, until an ignition of the test power was obtained. At each voltage level care was taken to see that an arc was formed in the test power even though an ignition of the power might not have been obtained. The V and V_i waveforms used in equation (1) were those obtained for the lowest capacitor voltage where an arc and ignition of the sample were obtained. It should be noted that the energies calculated by equation (1) were for a given gap length (length of power sample) and that longer or shorter gap lengths will probably result in different ignition energies.

4.2.2 Test Results

Probably, a more advanced testing technique developed during the program was that of obtaining actual voltage and electric current flow characteristics as the electrostatic discharge was fired into the sample powders during electrostatic discharge tests. From this, exact initiation threshold electrostatic spark energy values could be established. As reference, N-5 propellant paste and powder nitrocellulose were also tested. Results of all electrostatic characterization tests are shown in Table II.

4.3 System Electrostatic Test Results

Electrostatic measurements were taken on the Sweetie Barral system both during powder loading and powder tumbling. It should be noted that even though readings were taken over a week's span, naver during that week did the relative humidity go below 66%. A high level of relative humidity, 50% and above, is considared necessary for the safe continuous dissipation of static electricity.

A Keithly electrometer model 602 and a Keithly static haad detector model 2501 were used to perform tha tests.

Readings were taken on the following objects:

A. The entire length of the Sweetie Barrel chute, while Ball Powder was flowing both water wet and dry.

B. The tumbling Sweetie Barrel containing dry Ball Powder - inside and outside.

   1. Inside reading was taken from the surface of Ball Powder.

   2. Outside reading was taken from surface of Sweetie Barrel.

C. Tumbling Sweetie Barrel, both inside and outside barrel.

D. Tumbling Sweetie Barrel loaded with water-wet Ball Powder and graphite. Measurements were taken same way as tumbling barrel with dry Ball Powder.

E. Measurements of electrostatic leakage rate were also taken. These readings were taken immediately after the motion of the vessel or the powder flow was stopped. In each case, more than half the initial charge was dissipated in a very short time (~ one (1) second) and five or ten seconds later, no or very slight reading could be detected on the electrometer. This is an indication that charge dissipation is adequate.

F. Measurements were also taken while Sweetie Barrel chute was being cleaned with a cloth covered broom.

G. Measurements of tumbling Ball Powder were also taken after the addition of solvent, salt and tin dioxide. No appreciable differences between those readings and the readings from tumbling of dry Ball Powder was noticed.

Results of the above tests are shown in Table 4.3. Probably the most surprising result was that the charge density was considerably higher than what was estimated by previous investigation for chute flow.

TABLE 4.3

SWEETIE BARREL CHUTE SYSTEM ELECTROSTATIC TEST RESULTS

Component	System Condition	For Powder Conditions			
		Dry Ball Powder		Water Wet Ball Powder	
		Electrometer Reading	Charging Increased Coulomb/cm^2	Electrometer Reading	Charging Increased Coulomb/cm^2
Chute	While powder is flowing	*475v	2.06×10^{-9}	*180v	0.78×10^{-9}
	Immediately after stopping	None	-	None	-
	Clean chute with brush	*45v	1.96×10^{-10}		
Loaded Sweetie Barrel	Inside at powder surface	475	2.06×10^{-9}	280	1.22×10^{-9}
	Outside	180	0.78×10^{-9}	180	0.78×10^{-9}
	Stopped	200	0.87×10^{-9}	110	0.48×10^{-9}
	10 seconds afterwards	None	-	None	-
Empty Sweetie Barrel	Inside	120v	0.523×10^{-9}	-	-
	Outside	85v	0.37×10^{-9}	-	-

*Average reading over powder area.

Relative Humidity Range: 66% to 89%

Temperature Range: 64°F to 84°F

The value of 2.06×10^{-9} coulomb/cm^2 measured at the chute indicates that the charging due to powder flow on a chute is approximately 80 percent of maximum charge density permitted before breakdown and arcing. This represents a severe hazard if grounding is not adequate permitting electrostatic charge accumulations. Also, if dust or isopropyl alcohol fumes were present (during conventional salt coating), the discharge energies are adequate to promote initiation of dusts and vapors under proper conditions. (i.e. as indicated by Union Carbide engineers, stoichiometric mixtures of isopropyl alcohol and air can initiate at 0.02 millijoule.) Based on the 80% of maximum charging, the powder surface potential and energy in the chute are as follows:

$$V_{chute} = Q/c \approx 32.4 \text{ KV}$$

$$J_{chute} = 0.108 \text{ joules}$$

These values are significantly high to create a severe vapor explosion hazard in present salt coating operations.

4.4 Impact Sensitivity Test Results

The second hazard associated with the operation is that of powder impact or impingement when it hits the Sweetie Barrel. Two series of tests were conducted. First impact sensitivity tests were run on dry and wet samples using a Bureau of Mines impact tester using a 2 kg weight and a 20 milligram sample. The 50% probability results were obtained by using Bructon test methods. Results of these tests are shown in Table I. A significant increase in sensitivity was observed in the wet Ball Powder. (16 cm compared to 32 cm). As a result, a decision was made to conduct the second series of tests where both wet and dry Ball Powder were freefall dropped through a pipe ~ 20 ft vertically onto a metal surface. The tests were conducted at Badger Army Ammunition Plant. No sign of reactions were noted. The test was a good overstress evaluation.

5. PRELIMINARY HAZARDS ANALYSIS

This hazards analysis consists of a failure mode and effect(s) determination. Each procedure and/or station is examined for all possible modes of failure or error. Each failure is examined to determine possible impact upon the entire system and other procedures within the system. The results of this analysis are tabulated on Table III and important aspects of analysis are discussed in the following paragraphs.

The columns in Table III are identified as follows:

Process Description. Reference Figure 2.1 for the location of the procedure in the process and/or station or location on floor plan where it is being performed. Paragraph 2 briefly describes the procedures in the loading process.

Possible Failure. Listed in this column are possible failures or errors that could occur during the specific procedure. It is recognized that some of the possible failures listed carry a very low probability of occurrence. Also, some of the failures listed have already been prevented because of design provisions.

Potential Hazard. Listed in this column are the specific hazards or dangers associated with the occurrence of the particular procedural failure or error.

Hazard Level (or Effect). Here an estimate of the effect or extent of the hazard is made. Also the hazard is numerically categorized according to the following classifications.

Class I	Safe	No injury or damage
Class II	Marginal	Can be controlled without injury or major damaga.
Class III	Critical	Injury and/or major damaga.
Class IV	Catastrophic	Deaths, severe injury, major damage, failure occurs without warning and beyond control of Operator.

TABLE III

PRELIMINARY HAZARDS ANALYSIS DATA

Step	Process Description	Potential Failure	Potential Hazard	Hazard Level	Way to Prevent Failure	Way to Prevent Hazard	New Hazard Level
(1)	Roll buggy to chute	A. Buggy stop fails	Buggy falls off ledge	2	Buildup strong stop	Prevent failure	1
(2)	Attach ground strap	A. Does not occur	Electrostatic discharge	3	Built in safe-guard on buggy door	Good grounding and regular inspection	2*
(3)	Open buggy door	A. Buggy not over chute	Spillage	2	Built in safe-guard on buggy door	Regular inspection	1
(4)	Powder pours into chute	A. Improper grounding	Electrostatic discharge and possible powder initiation	4	Built in grounding and regular electrical checks	Maintain air humidity above 50% or install air ionizers	2
		B. Electro-static buildup pouring through air	Electrostatic discharge and possible initiation	4	Check moisture level on powder	Maintain air humidity above 50% or install air ionizers	2
		C. E.S. charge buildup in powder during pouring if chute is coated with powder	Electrostatic discharge and possible initiation	4	Check moisture level on powder plus regular clean-up of chute	Maintain air humidity above 50% or install air ionizers	2*
		D. Powder cakes up in chute	Impact or friction loads onto powder when dislodging	3	Control moisture level on powder and make provision to easily dislodge powder	Use soft brass and light weight tools properly grounded	

TABLE 111

PRELIMINARY HAZARDS ANALYSIS DATA
(continued)

Step	Process Description	Potential Failure	Potential Hazard	Hazard Level	Way to Prevent Failure	Way to Prevent Hazard	New Hazard Level
		E. Air vibrator fails	Same as above	3	Control moisture level on powder and make provision to easily dislodge powder	Use soft brass and light weight tools	2*
		F. Air vibrator applies severe loading on powder in chute	Excess electrostatic buildup in powder or impact loading	3	Proper checkout of vibrator and install damper	Same as 4A	2
		G. Vibrator causes structural damage to chute assy	Pinch or friction loads on powder	3	Sound vibrator installation designed to prevent chute fatigue	Install dampers on chute	2
(5)	Powder Flows from chute	A. Electrostatic buildup	E.S. Discharge and possible initiation	4	Proper moisture in powder	Same as 4A	2
(6)	Powder Impacts Sweetie Barrel (barrel stationary)	A. Dusting of powder	Electrostatic buildup and discharge with possible initiation	4	Keep humidity above 50% and keep inert gas on	Install air ionizers or keep humidity up	2*
		B. Powder impact loading	Possible initiation of powder	3	Spread out powder flow to minimized impact loading or reduce powder velocity	Keep impact loads down	2*

TABLE III

PRELIMINARY HAZARDS ANALYSIS DATA
(continued)

Step	Process Description	Potential Failure	Potential Hazard	Hazard Level	Way to Prevent Failure	Way to Prevent Hazard	New Hazard Level
		C. Inert gas flow stops	Same as 6A	4	Same as 6A	Same as 6A	2
		D. Inert gas permits electro-static buildup (i.e., combustion gases off stoichio-metric values)	Buildup of static in powder with possible initiation of solvent vapors	4	Same as 6A	Same as 6A	2
(7)	Powder impacts sweetie barrel (barrel rotating)	A. Increased dusting due rotation more severe than 5A.	Same as 6A	4	Same as 6A	Same as 6A	3
		B. C. D. Same as 6A					

Way to Prevent Hazard. This column indicates the things that can be done to either eliminate the hazard or minimize the effects of the hazard. In some instances these preventative measures have already been planned into the process.

Way to Prevent Failure. This column indicates the procedural or station modifications, precautions, or safety features required to prevent or minimize the possibility of the failure or error. Listed here also is the revised numerical category of the hazard if proper preventative procedures are taken.

5.2 Safety Margins and Results

The failure mode analysis as shown in Table III indicated two potential hazard areas. These areas showed hazard conditions prevalent after readily available corrective action could be taken.

First, in Ball Powder flowing in the chute and tumbling in the Sweetie Barrel, significantly high electrostatic energies could be generated. Actually, system tests revealed higher charging rates in the chute than expected by analytical techniques. Over 80 percent of theoretical maximum charge generations in actual cases as noted as compared to a predicted value of only 8 percent. The electrostatic energies generated on the powder in the chute at any one time was considerably less than that required to initiate Ball Powder (i.e. initiation threshold for wet powder of ~ 7.5 joules as compared to 0.1 joules generated). However, if powder coating solvent vapors were present in the area, they could be easily initiated by the charge generated in the chute or in the barrel depending on its mixture with the air. Calculations also showed that significant electrostatic energies (~2.8 joules) could be generated in the Sweetie Barrel during tumbling. Unfortunately, no good measure of powder capacitance in the barrel could

be made. Actually, in the barrel tumbling operation and on the powder chute, calculated charge voltages indicate a very high probability of corona discharge during operation. This does appear to present a problem for Ball Powder although it requires very high initiation energies (almost an order of magnitude greater than available energy). The greatest hazard occurs when solvent vapors or dust cloud formations occur around the operation. If a cloud initiation could occur, powder initiation could well occur depending on the location of the cloud.

From system electrostatic tests, no charge buildup occurs in the system and charge dissipation is very rapid (within 10 seconds). The results correlate well with calculations of powder time constants. Theoretically, wet Ball Powder dissipates charges in less than one millisecond in the chute and in the Sweetie Barrel. Conversely, dry powder requires more than 2 seconds to dissipate its energy. Also, the wet powder relaxation time is much more rapid than the travel time on the chute. Thus the situation is safe if the powder is wet, the air humidity is above 50 percent, and sufficient leakoff can occur. Actually, in wet powder the relaxation time can vary considerably due to powder surface conditions variability. Again it must be noted that any solvent vapor or dust suspensions near the operations constitutes a major safety hazard based on static electricity discharge.

The drop weight impact test results indicated that an increase in sensitivity exists for the wet Ball Powder in the Sweetie Barrel loading operation. One must be careful in interpreting the drop test results relative to the actual conditions expected in the system. The Ball Powder in the wet form (20-25 percent) can be initiated in one-half the height required for the dry Ball Powder. Unfortunately, correlation between impact test

energy levels and actual impact energy levels can lead one to erroneous results. The mass effects of the large quantity of Ball Powder impinging the Sweetie Barrel could essentially lower the initiation thresholds even further.

Actually, the full scale powder drop (impingement) test, 20 foot freefall in a pipe, indicated that no reaction was evident with either dry or wet powder. Thus the powder impact sensitivity does not appear to be a significant hazard.

6. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the modification proposed by Olin appears to preserve safety of the operation with the exception of two areas which require attention on a regular basis. One area deals with electrostatic charge buildup in Ball Powder which could, if discharged into the Sweetie Barrel, cause a possible powder dust or solvent vapor cloud detonation. Three possible means can be implemented to reduce this possibility as follows:

1. Increase surface area of chute in contact with the powder to minimize static charge buildup.

2. Maintain low velocity of powder movement in the chute to reduce electrostatic charge generation.

3. Provide proper and sound electrical grounding between buggy chute and Sweetie Barrel to bleed off electrostatic charge.

4. Control dusting or vapor cloud development to prevent explosion.

5. Use air ionizers or control humidity to minimize electrostatic charge generation.

It has been shown in this study that electrostatic charge buildups even in wet Ball Powder are sufficient to initiate a dust or vapor (solvent) cloud.

A much less significant second problem area relates to the apparent increase in impact sensitivity of the wet Ball Powder versus the dry Ball Powder. In the flow system as proposed, it is paramount that the powder velocity leaving the chute should be lower than that velocity at present conditions. In conclusion, the Sweetie Barrel chute system is considered safe. The following recommendations are being made to assure that the system safety will be maintained in production.

A. Both the chute and the barrel should be cleaned on a regular basis to prevent powder depositing on the chute which could prevent drainage of electrostatic charge from the powder.

B. Humidity control to greater than 50 percent and/or air ionizers should be installed in the process to minimize electrostatic discharges in air.

C. No tools which could carry electrostatic charge on them should be used to debridge powder in the chutes. Also, no hard, sharp instruments should be used.

D. All electrostatic grounds and bonds between the powder buggy and the Sweetie Barrel should be checked on a regular basis to maintain sound grounding. Resistance levels to ground should be less than 3000 ohms.

E. Flow of velocity of wet Ball Powder leaving the chute should not be greater than present speed to assure a reasonable safety margin against impact initiation of the powder.

F. If an air vibrator is attached to the chute, it should be thoroughly checked out to assure that no detrimental loads are transmitted to the Ball Powder and that the Ball Powder does not gain additional electrostatic charge buildup due to vibrator motion.

G. The powder buggy must be positively grounded electrically to chute. Also, the portable 5 ft chute section must be positively grounded to the permanent chute and the Sweetie Barrel.

H. Utilize a vacuum hood at mouth of Sweetie Barrel to extract solvent fumes during salt coating process and replace isopropyl alcohol with less electrostatic sensitive solvent.

Table

CALCULATED POWDER VOLTAGE AND ELECTROSTATIC ENERGY BASED ON E.S. GENERATION MEASUREMENTS

For Chute

C = 206 $\mu\mu f$
A = 3250 cm^2

For Sweetie Barrell

C = 34.9 $\mu\mu f$
A = 6550 cm^2

Component	System Condition	Dry Powder *Q (Coulomb)	Dry Powder Q/c Voltage	Dry Powder Q^2/cc Energy (Joules)	Wet Powder *Q (Coulomb)	Wet Powder Q/c Voltage	Wet Powder Q^2/cc Energy (Joules)
A. Chute	1. Powder Flowing	6.69×10^{-6}	32,400	0.108	2.54×10^{-6}	12,300	0.0156
	2. Immediately after stopping	-	-	-	-	-	-
	3. Clean chute with brush	0.64×10^{-6}	3,100	0.0011	-	-	-
B. Loaded Sweetie Barrel Tumbling	1. Inside at powder surface	13.5×10^{-6}	387,000	5.20	8.0×10^{-6}	229,000	1.84
	2. Outside of barrel	5.11×10^{-6}	146,500	0.72	5.11×10^{-6}	146,500	0.72
	3. Stopped	5.7×10^{-6}	163,500	0.94	3.15×10^{-6}	90,100	0.286
	4. 10 seconds later	-	-	-	-	-	-
C. Empty Sweetie Barrel Tumbling	1. Inside of barrel at surface	3.44×10^{-6}	98,900	0.34	-	-	-
	2. Outside of barrel	2.43×10^{-6}	69,500	0.17	-	-	-

*Calculated based on measurements listed in Table 4.3.

HAZARDS OF COPPER AZIDE IN FUZES

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I. Introduction

Lead azide is a primary explosive widely used as an ingredient in priming compositions, as the base charge in primers, and as the charge for detonating the secondary high explosive charges of flash, stab, and electric detonators. Thus it is an important ingredient of fuze explosive trains. Lead azide is certainly one of the best if not the best detonants available to explosive device designers. It has desirable properties of density, sensitivity, rapidity of build up to detonation, and thermal stability. It does have under certain circumstances, however, a major drawback, that is lead azide in the presence of moisture hydrolizes liberating hydrazoic acid. This hydrazoic acid can corrode certain metals, particularly copper, to form extremely sensitive and hazardous explosive compounds. That the concurrent use of lead azide and copper in fuzes may present a safety hazard has been neither widely recognized nor universally accepted.

Investigators of some recent accidents suspected that copper azide might have been present in the offending fuzes. But cursory examinations did not confirm this suspicion. Doubt about copper azide being the cause of these accidents arose and as a result the U. S. Naval Ordnance Laboratory (NOL) was asked to review the available information on copper azide and to form an opinion on its threat.

As a result of the review, NOL concluded that copper corroded by the hydrazoic acid liberated in the lead azide hydrolysis reaction has been, and can be, the cause of severe accidents. Incidently, subsequent to our review, copper azide was found in a number of the fuzes associated with one of the recent fatal accidents.

Also as a result of our investigation, we have recommended: (a) that the Navy remove from service fuzes that are not detonator safe, (b) that fuzes with potential copper azide problems be identified, (c) that a research program to find a suitable replacement for lead azide be undertaken, and (d) that where feasible fuze train components be sealed.

II. Chemistry of Copper Azide Formation

A. Types

The lead azide-copper reaction has been known since 1913 (1). Lead azide will react with moisture to produce hydrazoic acid (HN_3). This volatile acid (b.p. 35°C) (2) attacks copper and copper-containing metals with the formation of sensitive explosive products on the metal surface. While attack is usually concentrated in the vicinity of the source of lead azide, diffusion of the vapor can occur and result in the formation of the corrosion products at some distance from the lead azide container.

The chemistry involved in the corrosion process is set forth in the equations of 1. Hydrazoic acid is formed by the action of moisture on the lead azide. The hydrazoic acid attacks copper to give cuprous azide, CuN_3, which appears as a white film (3). Early literature reported the conversion of CuN_3 to normal cupric azide, $Cu(N_3)_2$, but recent work has proven that the cuprous azide is oxidized to monobasic cupric azide $Cu(N_3)_2.Cu(OH)_2$, a yellow-brown compound. X-ray diffraction study of corrosion layers on copper and brass has revealed cuprous azide located as the layer nearest the metal surface, with an outer coating of basic cupric azide (3). Further corrosion products, depending on the construction of the system, are the di-, tri-, or octa-basic cupric azides, yellow-green to green to blue-green in color (Figure 2). The presence of light accelerates the transformation of cuprous azide to the various cupric forms. After a period of time in ventilated containers the corrosion products observed are the di- or tri-basic cupric azides. Thus the tendency is for the very sensitive forms to be oxidized to insensitive varieties. All phases must, however, be presumed to exist together so that their varying degrees of sensitiveness must be considered.

A simple test to confirm the presence of copper azide is to apply one drop of aqueous ferric chloride solution which develops into an intense red coloration if copper azide is present in the corrosion.

B. Conditions of Formation

Moisture for the hydrolysis of lead azide can come from inefficient drying of the lead azide itself, from the air, from direct exposure to water or water vapor, and from other fillings in the same weapon. Due to temperature changes, a fuze can "breathe" permitting ingress of moist air. There is also frequently sufficient moisture available from the

H.E. fillings of conventional ammunition. Sometimes moisture can come from packing materials. The formation of copper azide is favored by high humidity. Temperature has less effect per se. At relative humidities higher than 90%, corrosion is quite rapid; at less than 80% RH the rate of corrosion is very slow. A bare copper strip will be corroded in 24 to 48 hours when hung above wet lead azide in a sealed beaker. When the strips are exposed to open flames, audible "pops" are heard. The rate of hydrolysis of lead azide is increased by traces of acidity. It has been shown that under adverse conditions of storage (120°F with added water), lead styphnate will increase the level of acidity and greatly accelerate the rate of hydrolysis of lead azide. Lead styphnate is commonly used with lead azide in priming mixtures and as an ignition charge in detonators.

C. Sensitiveness Characteristics

Studies have shown that the sensitiveness to impact and friction of copper azide deposits varies greatly. Lamnevik's (3) Impact and Friction data (Figure 3) indicate that cuprous azide is at least twice as sensitive as lead azide to both impact and friction. Monobasic cupric azide is twice as sensitive to impact but less sensitive to friction than is lead azide (3). The dibasic variety of cupric azide is however, less sensitive than lead azide to both impact and friction. Propagation from local ignition is more likely to occur during the initial stages of the corrosion cycle when cuprous and the monobasic cupric azide are present. Cuprous and monobasic cupric azide propagate in layers as thin as 0.85 mg/(cm^2) (4). Copper azides are very sensitive to electrostatic discharge. A piece of foil corroded with copper azide has been fired consistently from a 60 volt -20 erg discharge and occasionally at energies as low as 1 erg. Various "dropping" and "slamming" tests have demonstrated the increase in sensitiveness of samples corroded with copper azide over those covered with lead azide crystals.

The copper azides are not highly temperature sensitive. The five-second explosion temperature is about 216°C compared to 340°C for lead azide, and 325°C for lead styphnate.

III. Cases of Copper Azide Corrosion

A number of references to accidents and incidents involving copper azide corrosion can be found in the literature. A few of the significant ones will now be discussed.

A. U.K. Ordnance

British 20-mm Ammunition. The United Kingdom has had a number of incidents involving copper azide corrosion in 20-mm ammunition. Their troubles became apparent after WWII when ammunition was returned from storage overseas and later after storage in their country. The fuze involved in the British incidents was their fuze No. 254. The U.S. Mk 26 Mod 0 fuze was copied from it in WWII and is virtually identical. Fuze Mk 26 Mod 0 is shown in Figure 4. It can be seen from the figure that this fuze has no detonator safety. The sensitive primary explosive is not shuttered from the insensitive tetryl in the magazine. Thus the fuze is armed at all times, and, without benefit of a firing pin, detonates when target impact fires the detonator. The British fuze is constructed entirely of brass. The nose is closed with a brass disc, and the detonator cup is also made of brass. The fuze and detonator are unsealed and the detonator contains lead azide. The fuze contained in a 65-lb block can be dropped 30 feet without firing the detonator.

(a) ROF Swynnerton, 21 January 1948. Two men were killed from an explosion during the breakdown of 20-mm High Explosive Incendiary ammunition containing Fuze No. 254 (5). The "service operator" placed filled boxes, containing about 60 rounds each, on their sides on a felt covered table. The rounds were then spread over the felt to enable the operator feeding the breakdown machine to easily pick them up. After the machine separated the shell from the cartridge, the propellant powder was poured out of the cartridge into a hopper. Investigation of the accident revealed that a hole had been blown in the table top. This indicated that the explosion had occurred on or close to the table. Medical evidence revealed that the "feeding operator" had his arms outstretched and had half turned facing the service table. Involved in the accident was approximately two pounds of propellant in the propellant hopper and seven rounds of ammunition. Investigation showed that other rounds from the lots being broken down were badly corroded and that the cases containing the ammunition had been wet. The British concluded that the accident was caused by the presence of sensitive copper azide which fired when the "feeding operator" was in the act of feeding the breakdown machine. He had probably dropped a round only a few inches onto the felt covered table top. No attempt to actually identify the presence of copper azide in the corroded rounds was made. However, it is obvious from the fuze construction, i.e., the lack of a firing pin and no normally moveable parts, and from the normal insensitivity to impact of the round

that something had occurred to make the round supersensitive. The most logical explanation would be the formation of copper azide known to be easily capable of being formed in this ammunition.

(b) <u>ROF Swynnerton, 4 May 1949</u>. Four men were killed when a box of 20-mm HE Ammunition exploded while being loaded from a conveyor into a railway truck (6). The loading of the boxes, was carried out by six men. Two men lifted the box and placed it cornerwise on the conveyor. Two other men, one on either side of the conveyor, pushed the box up the inclined portion of the conveyor. Here it was held until the third pair of men lifted the box from the end of the conveyor and stacked it in the railway car. If the box was not immediately grasped by the last two men, one corner of the box could tilt over the edge of the conveyor and strike the bottom of the car or the top of the stack -- a maximum fall of six inches. Examination of the evidence showed that the box involved in the accident was at the top of the conveyor when the explosion occurred. The medical evidence showed that the middle two men still had their hands and arms close to the box. The last two men had not yet grasped the box and had their backs turned to it. The number of rounds exploding was less than the amount in a single box. It was probable that corroded rounds were present in the box which exploded. Other rounds being loaded were found in a corroded condition. The conclusion of the investigators of the accident was that the mishap was caused by one corner of the box of ammunition tilting over onto the floor of the van. This caused a detonator, over-sensitive because of copper azide corrosion, to fire. The detonation of one round then lead to the detonation of other rounds. No attempt was made to identify copper azide in the remaining rounds.

(c) <u>ROF Swynnerton, 30 June 1952</u>. A pile of 20-mm ammunition awaiting disposal exploded spontaneously. The ammunition was in extremely bad condition and many of the shells were heavily rusted. The most likely cause was attributed to the ignition of copper azide corrosion and the resultant firing of the detonator. The cause of the ignition was believed to be the high temperature of the day (7), which could have caused relative motion of parts by differential thermal expansion.

<u>40-mm Ammunition at ROF Pembrey and Irvine</u>. No accident occurred with this ammunition. However, copper azide corrosion was found and identified in the fuze. The fuze consists of the detonator, a lead azide filling separated by a shutter

from a lead of tetryl in brass. Investigations revealed that the risk of ignition by copper azide of the tetryl lead was remote (20). This was demonstrated by exposing shutter assemblies to hydrazoic acid. When the copper azide formed was ignited, it did not initiate the tetryl filling on the warhead side of the shutter.

3-Inch Fuze. Copper azide was found in 1959 in inservice 3-inch fuzes manufactured in 1952 and 1954. The fuze has an out-of-line mechanism. It contains an upper lead azide-filled detonator, a delay pellet, and a lower lead azide-filled detonator. Both detonators are in copper containers. These fuzes were involved in premature bursts. The rounds involved had been stored at Hong Kong. The investigation was started by breaking down 500 fuzes available in the United Kingdom and 1000 fuzes stored and present in Hong Kong. The Hong Kong investigation was started in April 1959. Copper azide was identified in 40% of the fuzes examined in Hong Kong and corrosion was found in all but 65 rounds.* Examination of firing records of rounds stored at Hong Kong revealed that between 1 January 1959 and April 1959, 7100 rounds were fired; six premature and 255 duds were noted. Copper azide was found in 32% of the 500 fuzes examined in the United Kingdom. Therefore, an experiment was arranged with 200 fuzes known to be from groups contaminated with copper azide.** The fuzes were modified, by removing the firing pins and all explosive components except the detonators and delay charge, and then were fired over water for recovery. Sixty-four fuzes were found with both detonators fired and the delay charge burned. An additional 40 were found with evidence of partial burning. Approximately 1100 other tests for possible causes of prematures other than copper azide were performed all with negative results. It was concluded by the British Ordnance Board that "there is no doubt that copper azide corrosion of the detonator can be held responsible for the prematures and blinds.*** The results of these field type firing tests taken together with the results of the laboratory tests with the 40-mm fuze as cited above, indicate that a well-designed shutter can eliminate prematures of warheads if the fuze detonator should fire prematurely in the out-of-line condition. The tests also show, however, that if premature firing occurs during the arming cycle, the warhead may be detonated.

* This corrosion was not necessarily copper azide.
** From data presented above, one would presume that copper azide corrosion was present in 30 - 40% of the fuzes tested.
***Blinds in British terminology is equivalent to duds in U.S. usage.

B. U. S. Ordnance

Mk 77 Mod 2 Fire Bomb. Between 27 June and 15 September 1966, there occurred at least four explosive incidents involving the use of the M157 fuze and M15 igniter. These items are components of the Fire Bomb Mk 77 Mod 2. The M157 fuze (Figure 5) contains the M26 Stab Primer which has lead azide in a gilding metal cup. This primer initiates a black powder booster charge. A burster containing lead azide and tetryl is in the M15 igniter (see Figure 6). Loud noises, flashes, and arcs occurred when the igniter and fuze were being assembled to the bomb. The explosive devices of the fuze and igniter were still intact afterwards. Copper azide was found and positively identified on the primers but this did not satisfactorily explain the incidents nor why the explosive devices had not fired. On 29 September 1966, after some fire bombs had been assembled, a marine was picking up the expended arming wires and brass Fahnestock clips, which are part of the fuze, when one clip exploded in his hand and flew about 50 feet. Investigation revealed the presence of copper azide corrosion on the clips. (See Figure 7.) The copper azide resulted from the attack of the hydrazoic acid vapor generated from lead azide in the burster. It was concluded and verified experimentally that the "cracking and flashing" of the clips resulted from static or RF initiation of the copper azide.

M52A1B1 Mortar Fuze. The M52A1B1 Mortar Fuze, used in 81-mm ammunition, was involved in a premature explosion in 1951 (8). Two marines were killed in a training mission when a round exploded 25 feet from the mortar. No precise cause was found by the board of inquiry. However, subsequent laboratory tests revealed that the effects of high temperature and humidity on lead azide of the M18 detonator and the M52 fuze could cause formation of hydrazoic acid and result in copper azide formation on the brass fuze slider. The M18 detonator consists of lead azide priming mix, lead azide, and tetryl in an aluminum cup. The laboratory tests (9) revealed the feasibility of the copper azide formed on the slider being initiated by friction encountered in the arming cycle.

20-mm - NAD McAlester, 25 January 1971. Three men were killed during the demilitarization process of 20-mm AA projectiles Mk 3 fuzed with the fuzes Mk 26 Mods 0, 1, and 2. (See Figure 4.) The fuze Mk 26, as already noted, was adopted from the British fuze No. 254 and thus is very similar to it. A significant exception is that the detonator

containers are nickel-plated brass* in the Mod 0 version, and aluminum in the Mods 1 and 2. As in the 254 fuze, the detonators themselves are not hermetrically sealed. The United States 20-mm round is manufactured to withstand a 40-foot drop. The demilitarization process normally involved six men. At the time of the explosion only three men were operating the equipment. One operator was taking projectiles from an open box and placing them on a belt feed conveyer which took the projectiles to the furnace. The projectiles had been previously separated from the cartridge cases and were repacked in metal boxes. Each box normally contained 680 rounds. The most probable cause of the explosion was a projectile, over sensitive with copper azide corrosion, firing when it was accidentally dropped. The exploding projectile set off adjacent boxes on the roller conveyor and then a pallet load of ten boxes (10). Copper azide was formed during storage of the unsealed projectiles in a humid atmosphere.

M404A2 Fuze - NAD Hawthorne, 25 May 1971. Three persons were killed on the renovation line of a 3.5-inch bazooka round, the fuze of which has an in-line explosive train (11). In the fuze, lead azide is in a copper cup with a copper disc seal and a brass triangle with a copper strip and firing pin immediately above. (See Figure 8, The most likely cause of the explosion was determined to be a reworked and improperly assembled rocket that fired when it was carelessly allowed to drop and impact against the bottom plug of the container into which it was being placed. Copper azide was only remotely suspected. Investigations revealed the presence on the copper parts of a blue discoloration which was believed to be the copper salt of a fatty acid (12).

IV. Discussion of Accidents and Incidents

Copper azides situated on moving parts can be initiated by friction. If present on exposed surfaces they can be initiated by static electricity as well. In weapons with in-line explosive trains this can cause catastrophic accidents during the handling process, or be a cause of premature detonations upon firing, for instance, within a gun barrel. A review of the accidents cited above reveals that fatalities

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* Very early models used brass detonator cups that were not plated. Some fuzes containing such detonator cups may still have been in the rounds for demilitarizing.

have occurred only in weapons incorporating uninterrupted explosive trains.* It is likely, in these accidents, that copper azide initiated the sensitive detonator and the complete explosive train, including the main charge filling, then functioned as it was designed to do. Fuzes designed according to accepted safety principles, such as those of MIL-STD 1316, preclude in-line explosive trains. New in-line fuzes should not get into military systems. It would seem wise to get rid of all in-line fuzing systems now used by the services. Due caution should be used in any demilitarization program involving uninterrupted fuze trains.

The assessment of the effects of the corrosion on safety and proper functioning of explosive trains with interrupted systems is more complex. Since hydrazoic acid can be a gas under military storage conditions any copper-bearing material in a fuze in which hydrazoic acid is formed may be subject to attack; this attack is not limited to materials directly in contact with the lead azide. In fact, there have been incidences where corrosion has been found on shutters of fuzes. That this corrosion can be ignited during the arming cycle has been demonstrated. Firing of copper azide in well-designed, shuttered fuzes is not likely to lead to serious accidents from main charge firings but will lead to duds.** However, if the azide corrosion is ignited late in the arming cycle of the fuze, prematures could conceivably occur before safe separation*** and cause serious and even fatal accidents. The accident reported in reference (8) is a possible example.

Available evidence shows that copper azide corrosion does occur and that the most sensitive of the corrosion products occur early in the corrosion process. Later these are transformed to more insensitive compounds. The rate of formation and transformation will vary from item to item depending on the individual item's temperature and internal humidity. These facts may account for the difficulty often experienced in proving that items from the same lots involved in accidents show no evidence of supersensitivity.

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* The accident with the mortar fuze M51A1B1 might well be an exception to this but cannot be proved. It seems only fortuitous that the British did not have fatalities with the three-inch fuze involved in so many prematures, including muzzle bursts.

** In a well-designed fuze, safe separation between weapon and launcher occurs before the fuze explosive train can communicate detonation to the warhead.

*** i.e. with improper fuze design.

The use of lead azide in primers and detonators became wide-spread a few years after World War II. The incompatibility of lead azide with copper (and many other metals) was known at the time that it was first put into Navy systems. Thus, the Navy loaded lead azide only in cups of aluminum or stainless steel. These are metals with which lead azide is compatible. However, early designers of detonators and fuzes containing lead azide did not appreciate the fact that one product of lead azide hydrolysis, namely hydrazoic acid, was gaseous well below normal storage temperatures. Because of this we find examples of detonators containing lead azide loaded in compatible cups but then inserted into unsealed systems containing copper, brass, and other high copper content metals. Such systems are potentially subject to copper azide formation because the gaseous hydrazoic acid can diffuse from the site of its formation and attack the copper.

When the gaseous nature of hydrazoic acid was understood Navy in-house designs of azide-containing explosive trains were accomplished, for the most part, without the use of copper or copper alloys. There are some recent designs of hermetically sealed Navy primers and detonators containing lead azide that have azide-compatible tin or silver plated copper containers. The plating and the solder seals are believed to be effective methods of avoiding copper azide corrosion.

Lead azide is the best initiating military explosive available. It has exceptional thermal stability, extremely rapid build up to detonation, high density, good flow properties, good priming ability, reasonable compatibility with other explosives and priming mixture ingredients, and is inexpensive and readily available. There is no suitable replacement material for it at present. That is why it is so widely used. The incompatibility problems with lead azide can be overcome by using only those construction materials with which it is compatible and/or by sealing it hermetically in its container so that moisture does not reach it and hydrazoic acid is not formed. The Navy is supporting effort on the hermetic sealing of nonelectric detonators by ultrasonic welding. Electric items are already being hermetically sealed by soldering and welding. These are effective techniques and are proving highly worthwhile. It is expected that the Navy will shortly issue an instruction prohibiting the use of lead azide in situations where copper azide could form unless the lead azide is hermetically sealed in its container. It is understood that the Army has recently prohibited the use of copper and copper alloys in fuzes containing lead azide.

Other methods for preventing copper azide corosion products have been investigated. These include non-metallic protective coatings such as varnishes, lacquers, and plastics, metallic platings such as tin, chemical inhibitors, sacrificial metals, and explosives other than lead azide. In general these methods have not lead to satisfactory explosive component, fuze train, and fuze designs.

V. Conclusions and Recommendations

This review has convinced us that copper azide formation in weapons does pose a threat and that consideration must be given to the prevention of copper azide in weapons.

Although copper azide has been the cause of many handling accidents, and although it must be considered a major suspect in accidents with unshuttered fuzes where it can be formed, it is not the only possible cause of such accidents. Other mechanisms for accidental firings can be conceived, and each accident must be investigated for its own peculiar circumstances.

Based on our findings the following recommendations are made:

(a) The military should as rapidly as feasible remove from service all weapon fuzes containing unshuttered explosive trains that employ primary explosives. If these trains contain lead azide and copper or copper-bearing metals they must be treated as being extremely hazardous.

(b) A review should be made of all in-service weapon fuzes to identify those that have potential copper azide problems.

(c) A research program should be undertaken to develop a new primary explosive having the good attributes of lead azide (sensitivity, density, build-up rate, thermal stability, etc.) and, in addition, having compatibility with the usual materials of construction for fuzes and explosive trains.

(d) Insofar as possible, fuze train explosive components (primers, detonators, delays, leads) should be designed to incorporate hermetic seals.

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MECHANISM OF COPPER AZIDE FORMATION IN AMMUNITION

$$\underset{\text{LEAD AZIDE}}{Pb(N_3)_2} + \underset{\text{WATER}}{H_2O} \rightarrow \underset{\text{BASIC LEAD AZIDE}}{Pb(OH)N_3} + \underset{\text{HYDRAZOIC ACID}}{HN_3} \qquad (1)$$

$$\underset{\text{COPPER}}{2Cu} + \underset{\text{HYDRAZOIC ACID}}{3HN_3} \rightarrow \underset{\text{CUPROUS AZIDE}}{2CuN_3} + \underset{\text{AMMONIA}}{NH_3} + \underset{\text{NITROGEN}}{N_2} \qquad (2)$$

$$\underset{\text{CUPROUS AZIDE}}{2Cu(N_3)} + \tfrac{1}{2}\underset{\text{OXYGEN}}{O_2} + \underset{\text{WATER}}{H_2O} \rightarrow \underset{\text{MONO BASIC CUPRIC AZIDE}}{Cu(N_3)_2 \cdot Cu(OH)_2} \qquad (3)$$

FIGURE 1

TYPES OF COPPER AZIDES

			COLOR
I	CUPROUS AZIDE	(CuN_3)	WHITE
II	MONO BASIC CUPRIC AZIDE	$(Cu(N_3)_2 \cdot Cu(OH)_2)$	YELLOW-BROWN
III	DI-BASIC CUPRIC AZIDE	$(Cu(N_3)_2 \cdot 2Cu(OH)_2)$	YELLOW-GREEN
IV	TRI-BASIC CUPRIC AZIDE	$(Cu(N_3)_2 \cdot 3(Cu(OH)_2)$	GREEN
V	OCTA-BASIC CUPRIC AZIDE	$(Cu(N_3)_2 \cdot 8CuO.7H_2O)$	BLUE-GREEN

FIGURE 2

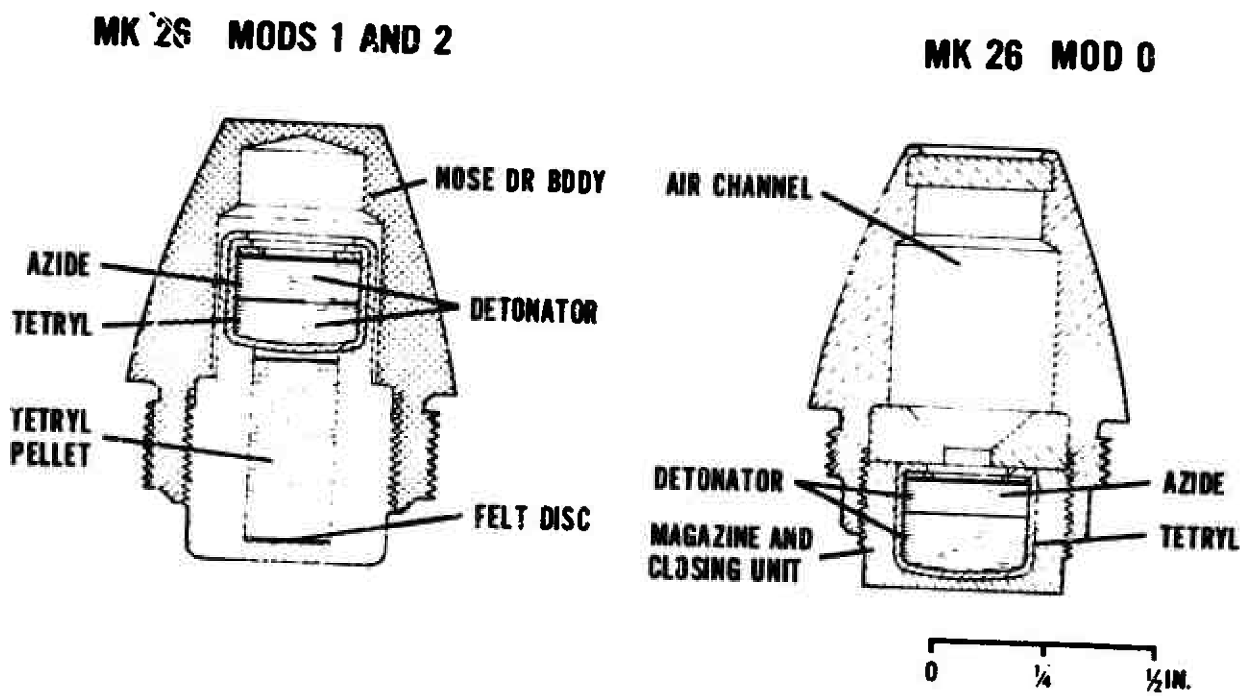
SENSITIVITY OF SEVERAL METAL AZIDES

	PbN_6 (LEAD AZIDE)	CuN_3 (CUPROUS AZIDE)	$Cu(N_3)_2 \cdot Cu(OH)_2$ (MONO BASIC CUPRIC AZIDE)	$Cu(N_3)_2 \cdot 2Cu(OH)_2$ (DI-BASIC CUPRIC AZIDE)
IMPACT 130 g. STEEL BALL ≈ 50% HEIGHT (CM)	20	10	10	70 (NO FIRES)
FRICTION (g)	80	30	120	120
ELECTROSTATIC (ERGS)	1500	1		
THERMAL (°C)	340	216		

NOTE: LOWER NUMBER MEANS GREATER SENSITIVITY

FIGURE 3

MK 26 MOD 0-2, FUZE, PD



NOTE: MOD 0: ALL BRASS
MOD 1: STEEL OR BRASS MAG, ZINC BODY
MOD 2: BRASS MAG, BRASS BODY (MOD 0 TYPE)

FIGURE 4

CONSTRUCTION OF M-157 FUZE

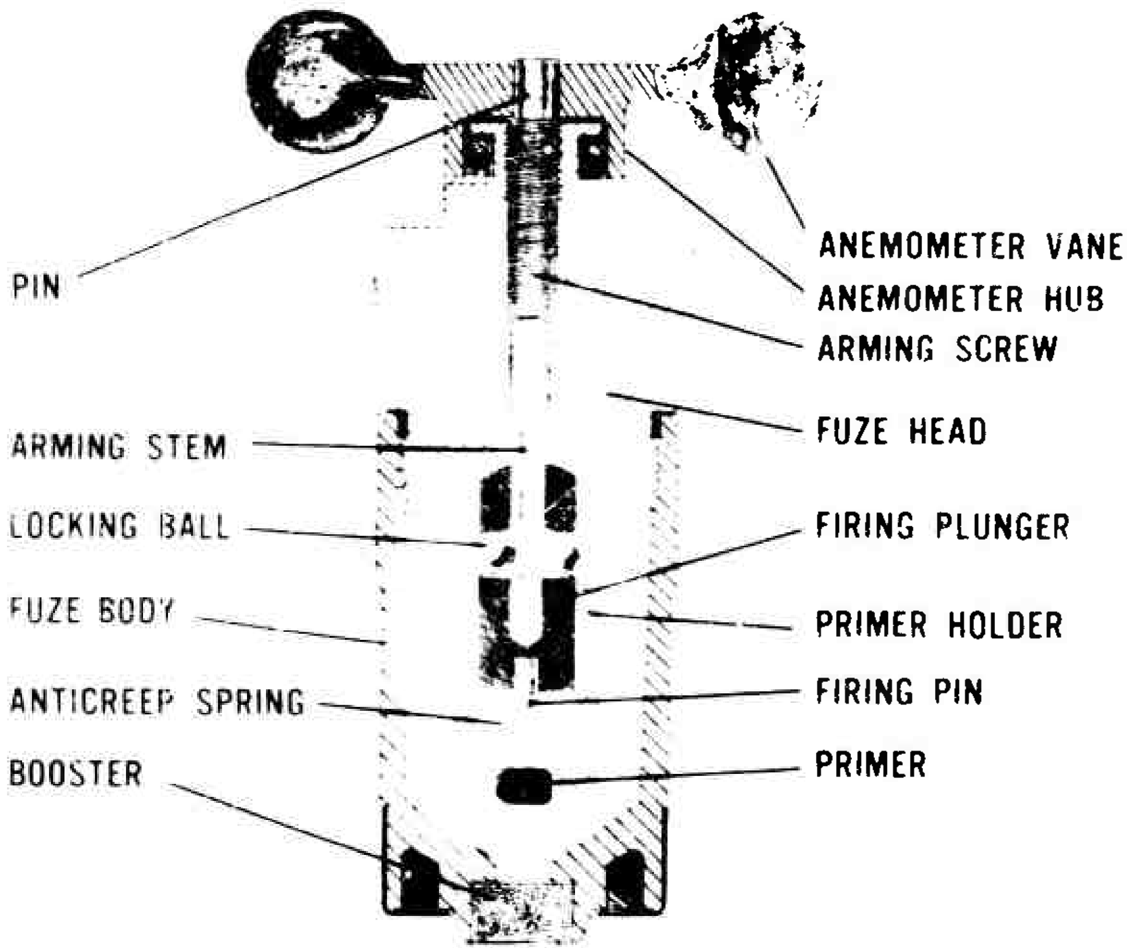


FIGURE 5

CONSTRUCTION OF M-15 IGNITER

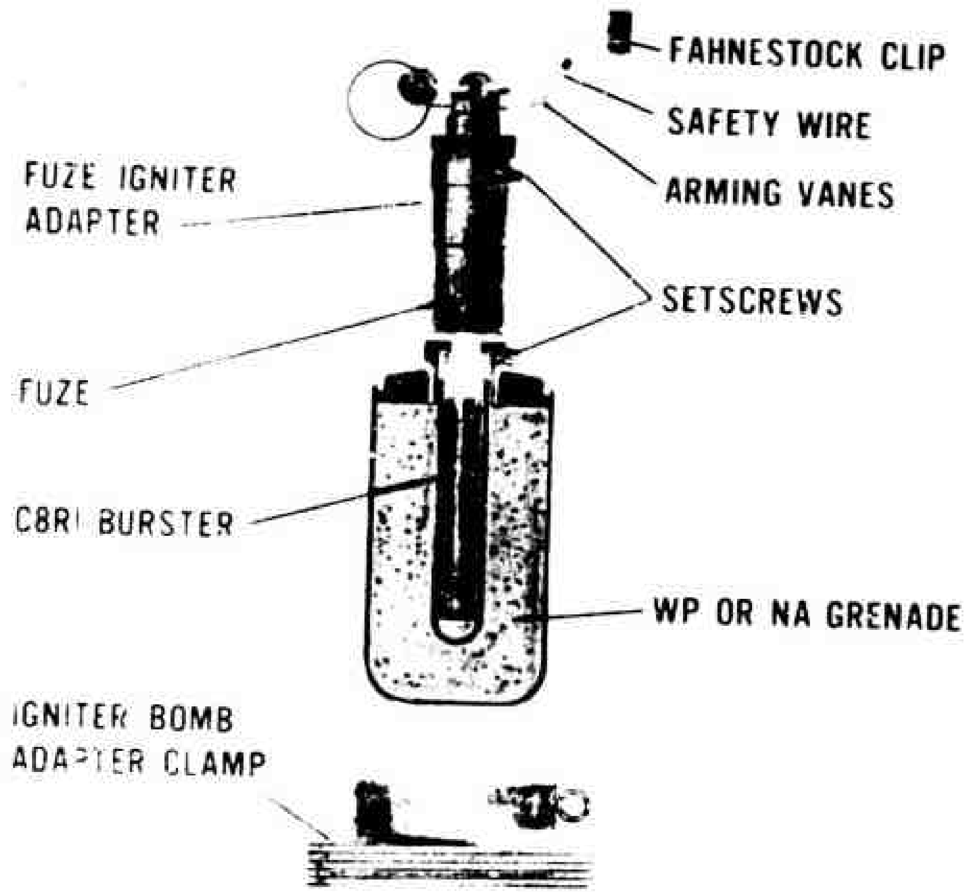


FIGURE 6

FUZE WITH CORRODED FAHNESTOCK CLIP

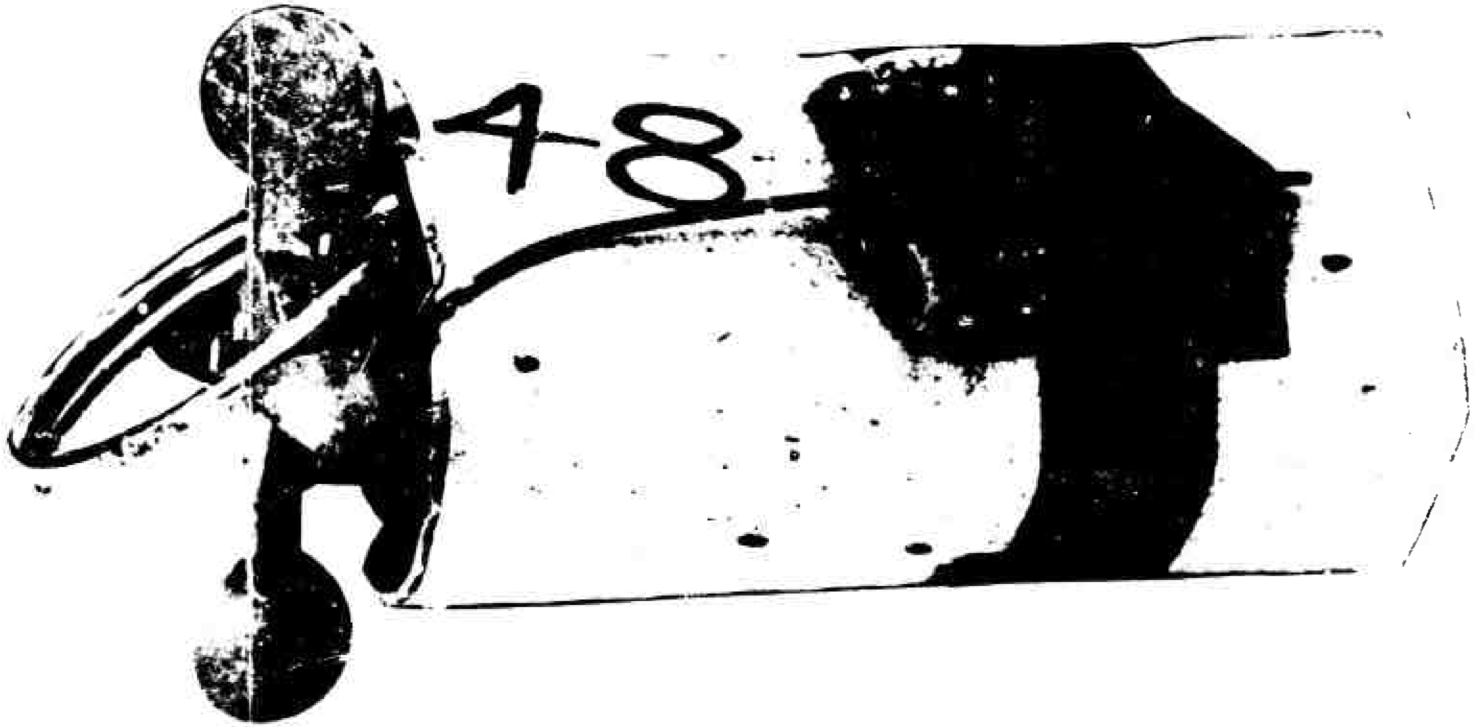


FIGURE 7

NOL

M404A2, FUZE, ROCKET, BD

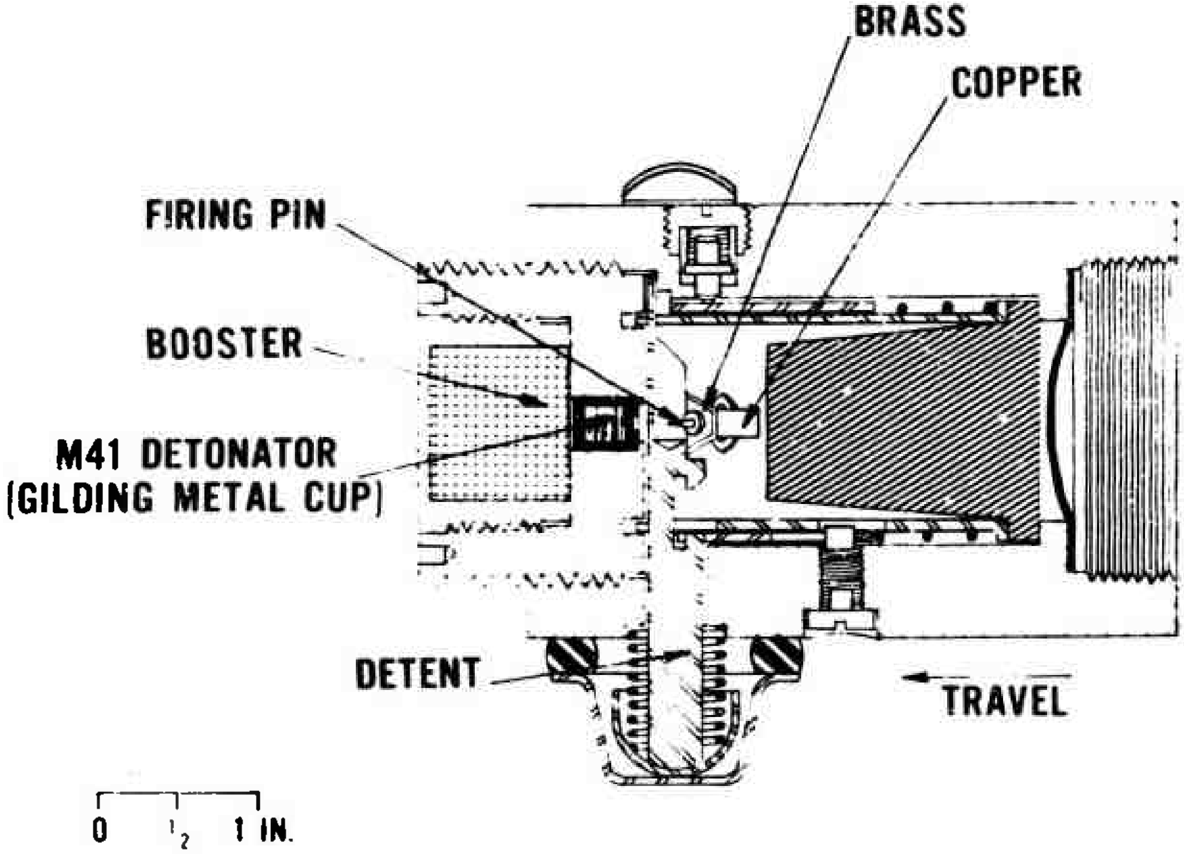


FIGURE 8

SENSITIVITY OF FULLY LOADED SMALL ARMS MAGAZINES TO BULLET IMPACT

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ABSTRACT

Single shots of 5.56mm M193 and 7.62mm M80 ball ammunition were fired against plastic and aluminum magazines fully loaded with standard brass cased 5.56mm M193 ammunition. The purpose of these tests were to determine the sensitivity of the loaded magazines to bullet impact and to develop a data baseline from which new ammunition could be judged. A multi flash x-ray system was used to measure the bullet striking velocity and impact orientation. A chromel-alumel thermocouple was used to measure the temperature of the environment directly behind the magazine and sustained burning and flame propagation was recorded. The striking velocity range was from the ballistic limit velocity to about 1300m/sec. The results of the 5.56mm M193 tests against side on center impact on fully loaded magazines are presented.

INTRODUCTION

A program was initiated whereby baseline data would be generated on the vulnerability of existing and new lightweight small arms ammunition. Techniques of obtaining these data were to be investigated and the one that provided the most useful information was to be adopted as the standard. Of the several methods investigated, it was decided to use the x-ray flash radiography method for obtaining ballistic data worked out by the Ballistic Research Laboratories (BRL). The task and objectives of the BRL are shown on Figure 1.

Program

The program is outlined on Figure 2.

Impact Conditions

The four impact conditions are shown on Figure 3. Each test was checked visually to insure the desired impact was obtained.

Experimental Set-up and Instrumentation

Experimental set-up and instrumentation used in these tests is shown on Figure 4.

Eight x-ray tubes are utilized to obtain records needed for the fragment data reduction. Four pairs of tubes, each pair arranged orthogonally at known distances from each other and the film plane are used to obtain four orthogonal views of the event. Two pairs located in front of the target are used to obtain records from which the projectile striking velocity and orientation are calculated. Two pairs of tubes located behind the target are used to obtain records from which the residual velocity, residual weight and spatial distribution of the projectile and target fragments are calculated. The tube pairs are pulsed sequentially at preset times. The sequence is started when the projectile breaks a printed circuit placed in the path of the projectile. Celotex sheets are stacked several feet behind the target to permit fragment recovery. Ten megacycle counters are used to check the preset times and monitor the time between flashes during the event. A computer program[1]*takes data read from orthogonal radiographs, transfers film coordinates to space coordinates, correlates the images and calculates velocity weight and spatial distribution for each fragment.

*1. C. Grabarek and L. Herr, "X-Ray Multi-Flash System for Measurement of Projectile Performance at the Target," Ballistic Research Laboratories Technical Note No. 1634, September 1966.
"A Computerized Method of Obtaining Behind the Target Data From Orthogonal Radiographs." Unpublished.

TASK NO. 2: TERMINAL EFFECTS OF BULLETS AND FRAGMENTS.

OBJECTIVES: 1. TO DEVELOP A TEST METHODOLOGY TO MEASURE THE PERFORMANCE OF AMMUNITION IMPACTED BY FRAGMENTS AND BULLETS.

2. TO DEVELOP A BASELINE FOR CURRENT AMMUNITION FROM WHICH NEW AMMUNITION CAN BE COMPARED.

3. TO DEVELOP A MODEL WHICH WOULD PREDICT THE LETHALITY AND VULNERABILITY OF NEW AMMUNITION.

Figure 1 SMALL ARMS AMMUNITION EXPLORATORY DEVELOPMENT

PROJECTILES:		7.62mm BALL BULLET 5.56mm BALL BULLET
TARGET	:	ALUMINUM AND PLASTIC MAGAZINES FULLY LOADED WITH BRASS CASED 5.56mm M193 BALL BULLETS.
MEASURE	:	STRIKING VELOCITY AND ORIENTATION, OF BULLET BEFORE TARGET IMPACT. RESIDUAL VELOCITY, RESIDUAL WEIGHT, SPATIAL DISTRIBUTION OF THE PROJECTILE AND TARGET FRAGMENTS AFTER PERFORATION. TEMPERATURE AND NUMBER OF ROUNDS BURNED.

FIGURE 2. PROGRAM

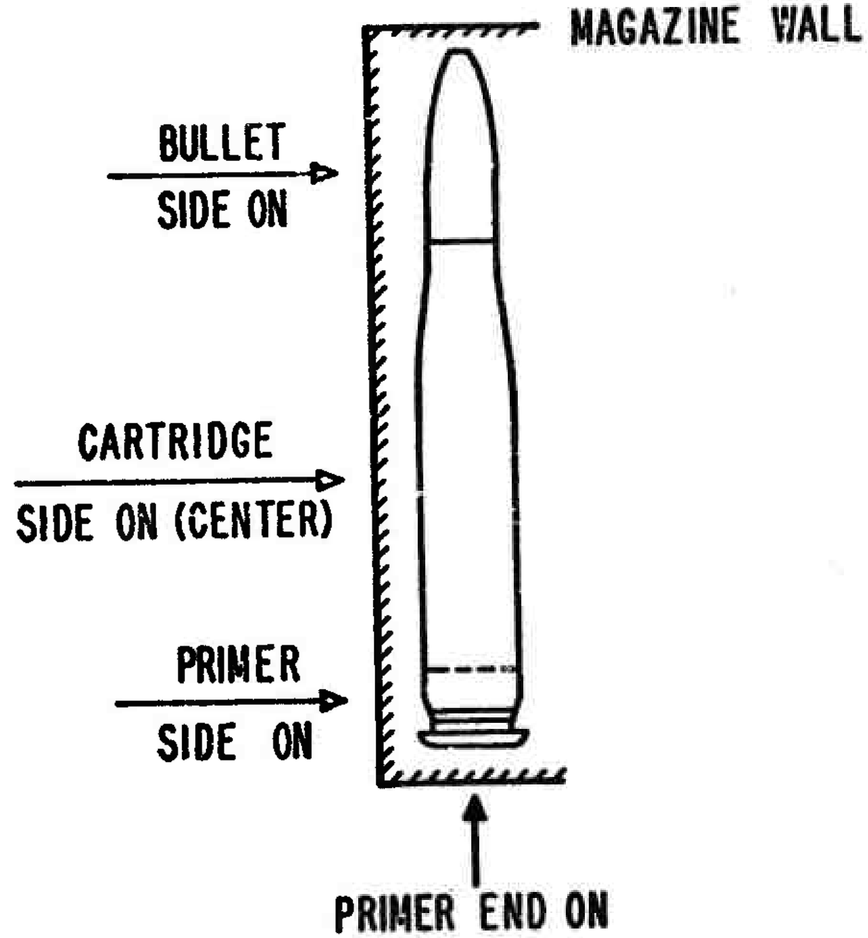


Figure 3 IMPACT CONDITIONS FOR PLASTIC AND ALUMINUM MAGAZINES LOADED WITH 5.56 MM M193 BRASS CARTRIDGES

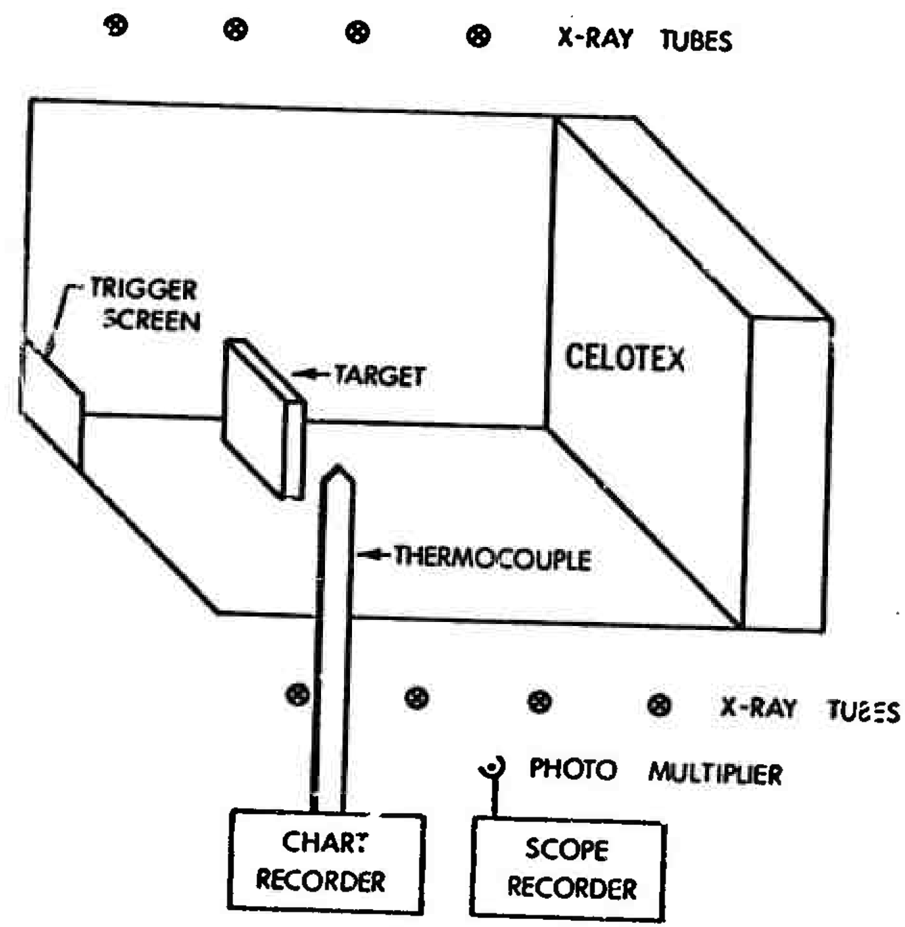


Figure 4 Experimental Set-up

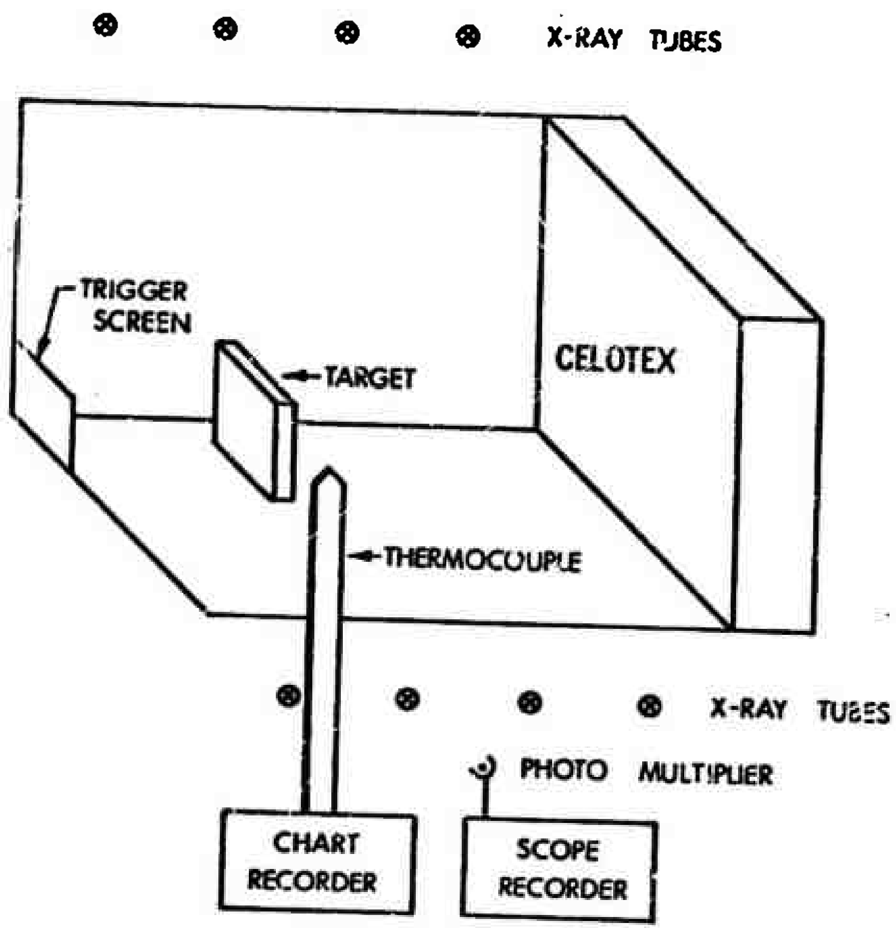


Figure 4 Experimental Set-up

Temperature-time records are obtained by utilizing a 10 mil diameter chromel-alumel thermocouple placed 1.27 cm behind and 2.54 cm from the aim point. The output of the thermocouple is recorded on a chart recorder. The system is calibrated such that pen deflection is equivalent to voltage output which in turn is converted to temperature. Writing speed determines the time parameter. The system is triggered at projectile impact.

TEST RESULTS

Radiograph

A typical radiograph (side view) of the event is shown on Figure 5. The projectile is shown before target impact, and 140 and 330 μsec after target perforation. For this paper, the residual velocity and weight of the largest, fastest projectile fragment will be discussed.

Projectile Residual Velocity

The ratio of the residual velocity/striking velocity, Figure 6, is plotted as a function of the striking velocity, for the 5.56mm M193 ball bullet against plastic and aluminum magazines fully loaded with standard brass cased 5.56mm M193 ammunition. The curve shows that the residual velocity approaches the striking velocity for striking velocities over about 500 m/sec. Below 500 m/sec the curve shows that the aluminum magazine offers more resistance to penetration. For example, at a striking velocity of 300 m/sec the residual velocity is about 80% of the striking velocity for the plastic magazine and only about 70% for the aluminum magazine. The curve also indicates that the ballistic limit velocity is higher for the aluminum magazine. The ballistic limit velocity is defined as the point of intersection of the curve and the abscissa, i.e., the striking velocity which results in zero residual velocity. Below 500 m/sec the curves separate and will intersect the abscissa at different points.

Residual Weight

The residual weight of the largest projectile fragment is shown on Figure 7. The curve shows that above 500 m/sec the projectile perforates the target intact. Above 500 m/sec the projectile breaks up. The difference in residual weight was not discernable for the projectile attacking the plastic and aluminum magazines.

Temperature-Time

Temperature-time curves are shown on Figure 8. The bullet impact was on the cartridge side at a striking velocity of 1006 m/sec. The thermocouple started to record, for these tests, approximately 1 to 3.5 sec after impact, and reached peak temperatures of 1500°F, 830°F and

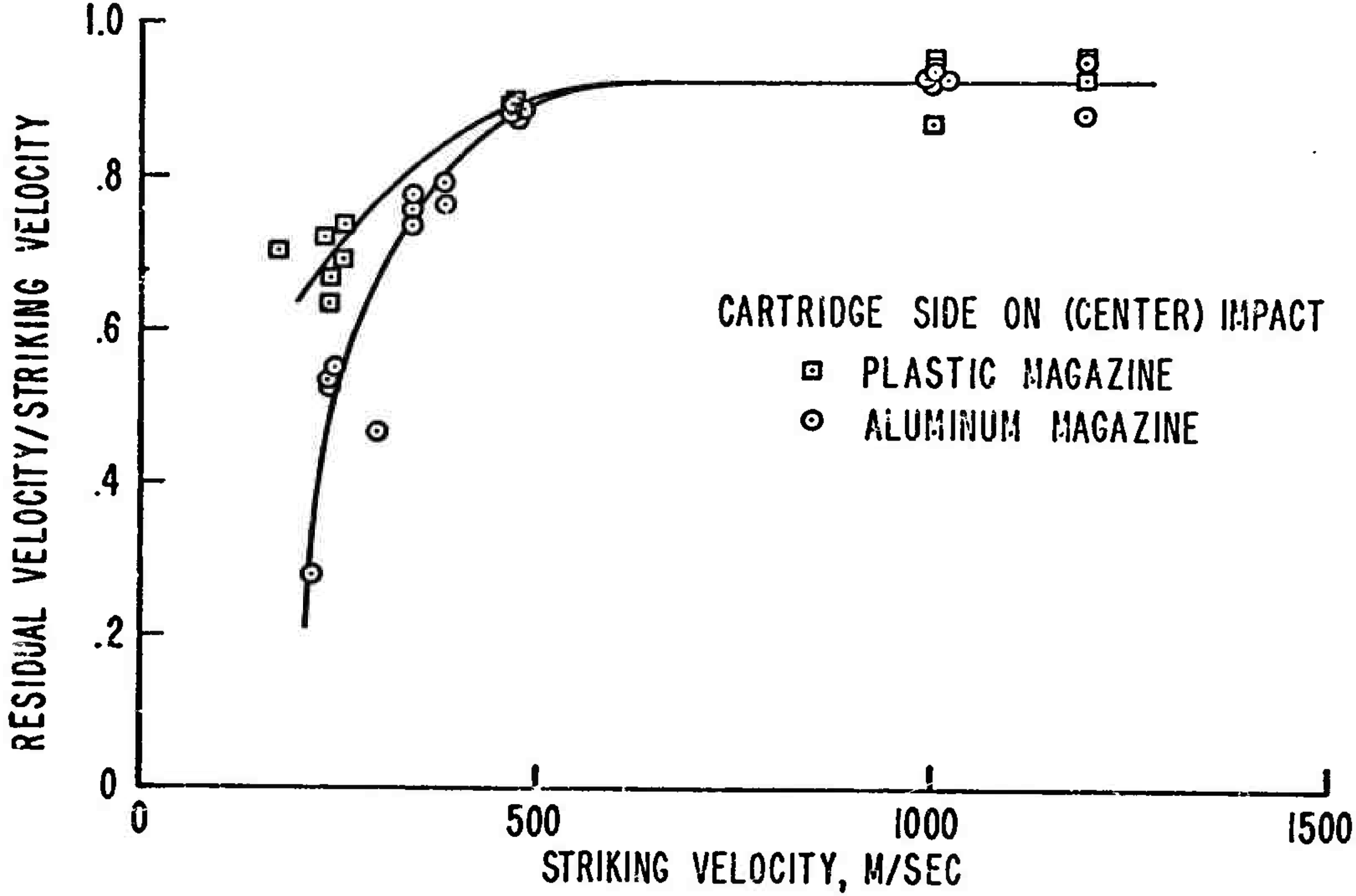
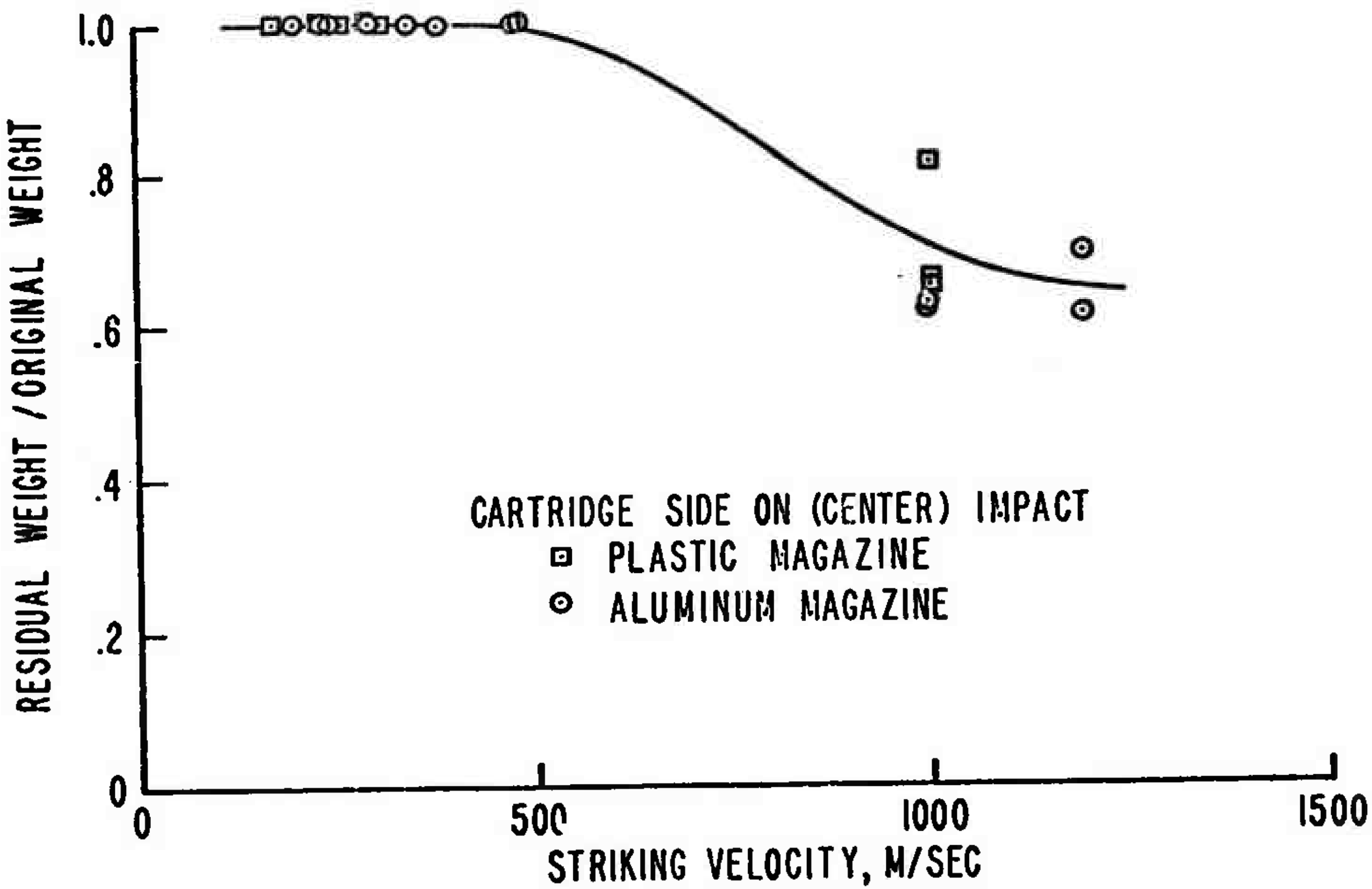
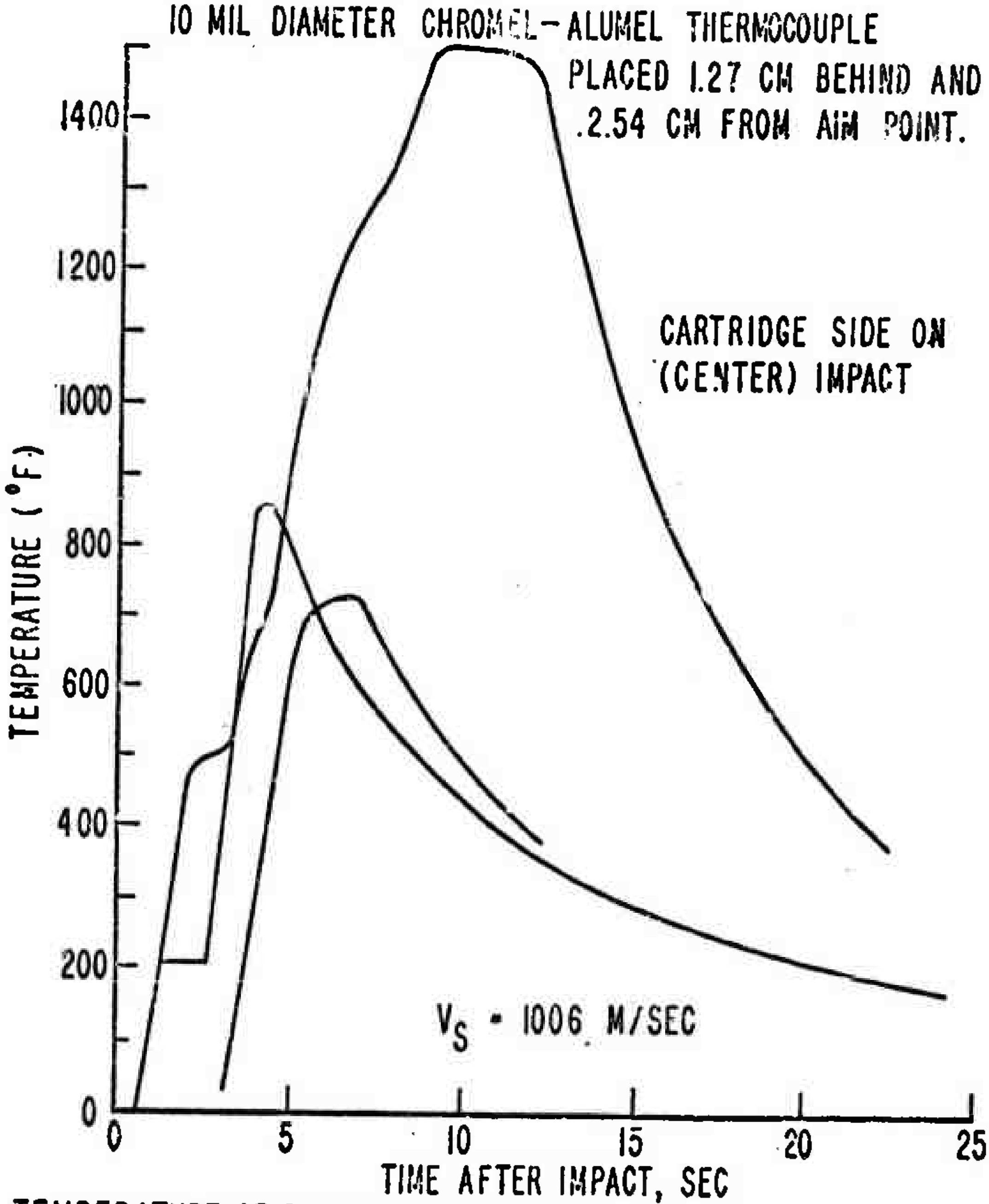


Figure 6 VELOCITY OF 5.56 MM, M193 AFTER PERFORATION OF MAGAZINE LOADED WITH 5.56 MM, M193 BRASS CARTRIDGES



WEIGHT FOR 5.56MM, M193 AFTER PERFORATION OF MAGAZINE LOADED WITH 5.56MM, M193 BRASS CARTRIDGES

Figure 7



TEMPERATURE OF PROPELLANT FROM PLASTIC MAG. LOADED WITH 5.56MM, M193 BR. CART. AFTER PERF. BY 5.56MM, M193 BULLET

Figure 8

700°F at approximately 10 sec, 4.5 sec and 6 sec after impact respectively. The reason for the lower peak temperatures was due to the proximity of the thermocouple to the flame. The temperature decreases with time as shown in Figure 6.

NUMBER OF ROUNDS BURNED

For side on impacts the probability of obtaining sustained burning is given on Table 1. The data were obtained by three methods, (1) thermocouple output, (2) photomultiplier output, and (3) visual inspection of the magazines. No trend was established relating the burning of propellant to the striking velocity. For the aluminum magazine, burning occurred about 9% of the time, in a sample of 69 rounds. For the plastic magazine, burning occurred about 20% of the time, in a sample of 82 rounds. The striking velocity for these tests varied from about 100 m/sec to 1300 m/sec.

SUMMARY

A method using flash radiography and a thermocouple can be used to measure the sensitivity of fully loaded small arms magazines. The sensitivity in this case are the projectile/target interaction in terms of behind-the-target effects, temperature of the environment behind the target and burning of propellant as a function of striking velocity. These parameters can be used to compare new ammunition and provide input to vulnerability analysis.

Table 1

NUMBER OF ROUNDS BURNED

CARTRIDGE SIDE ON CENTER IMPACT

Aluminum Magazine

Striking Velocity Interval m/sec	Average Striking Velocity m/sec	Number of Rounds	Number of Rounds Burned
1200-1300	1205	2	0
1000-1100	1010	5	2
900-1000	990	10	4
700- 800	750	6	0
600- 700	651	6	0
500- 600	553	5	0
400- 500	452	16	5
300- 400	357	11	0
200- 300	248	5	0
100- 200	185	3	0

Plastic Magazine

Striking Velocity Interval m/sec	Average Striking Velocity m/sec	Number of Rounds	Number of Rounds Burned
1200-1300	1219	2	0
1000-1100	1004	6	4
900-1000	927	24	10
800- 900	867	11	2
700- 800	751	6	0
600- 700	654	10	2
500- 600	546	7	0
400- 500	481	7	0
200- 300	242	9	0

EXPLOSIVES & AMMUNITION SENSITIVITY TESTS

by

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Summary

An experimental program was initiated to determine safe separation distance for ammunition items and in-process explosive materials as part of the overall program entitled "Safety Engineering in Support of Ammunition Plants", the highlights of which are covered in Mr. Saffian's presentation at this seminar.

The test program involved various ammunition items (155mm Composition B loaded shell, 2.75" Rocket Warheads etc.) and in-process explosives (55# TNT boxes C_4 blocks and buckets). Tests were run with and without shielding between ammunition items and in-process materials.

The results indicate that effective safe separation distances between ammunition items without using shields are excessive for practical operational purposes. However, shields of one kind or another were effective in preventing propagation of detonation at reasonable separation distances. The presently required distances between the TNT boxes containing bulk explosives on a conveyor were found to be excessive and could be reduced for the purpose of preventing propagation of detonation between boxes without sacrificing safety.

Similar tests are planned with other ammunition items and in-process explosive materials. The purpose of these tests is to update the present safety regulations contained in the Army's Safety Manual AMCR385-100 concerning spacing of ammunition items and bulk explosives on a conveyor.

Introduction

As part of the Army's plant modernization program Picatinny Arsenal undertook a program to establish safe separation distances between individual ammunition items and in-process materials. Although data relating to safe spacing between ammunition end items and bulk explosive boxes (in-process materials) are specified in Chapter 17 of the Safety Manual AMCR385-100, the information on certain ammunition end-items and

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in-process materials, presently in production, is not available. In addition, the remaining data have no substantiative statistical validity. The test program discussed in this paper was the result of the above-cited shortcomings.

Although several ammunition items and in-process materials were either tested recently or are presently under investigation the paper will primarily discuss tests conducted with 155mm Composition B loaded projectiles and 55 lbs TNT boxes. Table 1 lists all ammunition end-items and in-process explosives which are discussed in this paper.

Safe Separation Test for 155mm Composition B Loaded Projectiles

This test series consisted of 3 parts:

Part 1 dealt with establishment of safe separation distance between individual projectiles without shields.

Part 2 dealt with the establishment of a minimum safe separation distance using shielding between the individual projectiles.

Part 3 dealt with performing confirmatory tests at the acceptable confidence level and reliability based on results obtained in Part 2.

The test set-up for Part 1 is shown in Figure 1 (vertical orientation) which simulates a condition during the melt-pour operation. It consisted of four acceptors arranged radially with the donor shell at the center. Seven tests ranging in distance from 24" to 96" were performed. Figure 2 shows a horizontal orientation simulating a condition in the assembly operation of Load, Assembly & Packing (LAP) facility. It consisted of a donor shell on each side of the donor. The separation distances varied from 48" to 72". The domino vertical orientation is shown in Figure 3. Five acceptors were positioned on each side of the donor. This arrangement was used with two separations, namely, at 18" and 24" between shells.

The separation tests (Part 1) were performed starting with 2' separation between the donor and acceptor charges and increasing the distance in 1 or 2' increments as it became evident that propagation into one or more acceptor charges occurred at those distances. The minimum distance at which detonation propagation did not occur was 96" in a vertical position and 72" in a horizontal position. However, as can be seen from Figure 4 the penetration of the donor fragment into one of the acceptors at 72" separation was such that detonation

propagation could have occurred if more similar tests were performed. Since these separation distances were excessive for operational purposes, there was no point in pursuing these tests any further without using some kind of a shield between the projectiles.

The tests regarding domino orientation (shown in Figure 3) resulted in detonation propagation to no more than two acceptors on each side of the donor shell (at 18" separation). These tests demonstrated however that detonation propagation will not continue indefinitely and thereby a degradation in explosion propagation will be achieved. This occurrence was observed also in tests conducted previously by the British Ministry of Defence. The occurrence of this phenomenon will be of importance in the design of these LAP facilities where material handling systems will permit movement of individual 155mm projectiles around and/or through dividing walls. A summary of results on separation tests is shown in Table 2.

In Part 2 shields were used between the donor and acceptor charges. A typical test set-up using steel or aluminum plate shield between 2 adjacent shell is shown in Figure 5. The wall thickness of the shields varied from ½" to 1" (for steel) and from 1" to 2" for aluminum. The clear separation distance between the donor and acceptors ranged from 9" to 24". In addition, tests were performed using 2" diameter steel and aluminum bars and 3½" steel and aluminum pipes. The test set-up using the above rods as separation shields between the donor and acceptor are shown in Figure 6 and Figure 7. The clear separation distance between the shells was 18" and 24".

As may be seen from Table 3 all types of shields used (plate-type, bars and pipes) were effective in preventing detonation propagation at 18" clear separation distance, but their weights and the displacements of acceptors they caused varied over a wide range. However, at separation distance of less than 18" propagation occurred with both ½" steel and 1" aluminum plate shields, and consequently the distance was established at 18". A surprising aspect of these test series was the fact that both the steel and aluminum rods as well as pipes were effective and highly efficient in preventing detonation propagation at 18" separation. However sufficient tests were not run to definitely substantiate the above conclusion.

Part 3 consisted of performing 50 confirmatory tests involving 100 acceptor charges. Twenty-five tests were performed using ½" steel plate shields and 25 using 1" aluminum plate shield. Figure 8 shows a family of curves relating the number of tests to the probability of the occurrence of propagation for different values of confidence levels.

Safe Separation Distances Between 55 lbs TNT Boxes

The purpose of these tests was to determine spacing required to prevent propagation of boxed TNT being transported on ammunition load lines. The explosive tested was TNT type 1-Flake, packaged in cardboard containers 1.2 cu. ft. 66 lbs net weight.

The boxes were placed on a stand as shown in Figure 9 or on a section of a conveyor with a cover as shown in Figures 10 and 11 at the height of 30" from the ground. This simulates the approximate height of a conveyor used in production lines. The separation distance was measured as the clear distance between the adjoining items. The center item served as the donor in each test.

The results of preliminary tests indicated that no propagation will occur when the boxes are separated 8' or more apart. When the boxes were placed on a conveyor with a cover, burning of TNT occurred up to 16'. Without the cover one box out of a total of 42 boxes started to burn at 12' separation. The results of these tests have been evaluated and summarized in Table 4. In order to maintain a practical conveyor speed for required production rates with an acceptable level of safety a separation distance of 12' between TNT boxes was chosen. Twenty-five confirmatory tests at 12 separation (with covers) involving 50 acceptors were conducted without a single propagation.

The problem remains, however, of spread of fire from box to box at these distances. We have not attempted in these test series to establish, statistically, a valid safe separation distance to prevent a spread of fire between TNT boxes. Development of suitable deluge system is planned. It will be designed so that when an explosion occurs in one area of the plant, production in other areas will continue without stoppage.

Safe Separation Tests for 2.75" Rocket Warheads

Tests performed with 2.75" rocket warheads were basically similar to tests performed with 155mm projectiles discussed previously. It consisted of 2 tasks. The first task was of an exploratory nature and involved the placing of various types of shielding materials between the donor and acceptors and examining data for evidence of detonation propagation. The second task consisted of 25 confirmatory tests using the optimum types of shield and warhead spacing at which no detonation propagation took place. Still photographs of the exploratory tests are shown in Figures 12 and 13.

The results of the first few tests led to the conclusion that a shield consisting of a 2" diameter steel bar is as effective as one consisting of 3/8" flat steel plate, in preventing detonation propagation.

The 25 confirmatory tests all showed very similar results in the damage. Through a study of the high speed film and resultant damage, there was no visible difference between tests using a shield of 2" bar at 9" spacing and tests using a shield of 2" bar at 12" spacing.

M18A1 Mine Separation Tests

This program consisted of a test series using M18A1 mines and 1.5 lbs C_4 blocks. The objective of this test series was to select a side-to-side spacing which would prevent propagation of detonation (or deflagration) from one item to the next.

The first test series consisted of 10 exploratory shots to determine total spacing (Figure 14) and 50 confirmatory tests at that spacing. A spacing of 10" between C_4 blocks was confirmed as safe separation distance between the blocks.

The second series (20 tests) was conducted using the Bruceton method of sensitivity testing. The results of this series indicated that a 10.2" spacing between the mines provides a level of reliability of 99%.

The tests of these two series showed that an M18A1 mine is relatively insensitive to the blast effects of the donor when separation exceeds 6" regardless of the lateral orientation of the donor. This is based on the fact that no detonation occurred at 7" or greater spacing. From the test data a side-to-side separation of not less than 10.2" will be necessary to adequately insure that neither detonation propagation nor deflagration into the acceptor will occur.

Concluding Remarks

The tests performed to date clearly indicate that the present safety requirements for safe separation of explosive end-items or in-process materials are inadequate. So far we have been conducting tests in cases where no information concerning safe separation distance is presently available. At present we are in the process of conducting separation tests with 60 lbs Composition B and 50 lbs C_4 buckets.

The information on these tests will be available shortly. However, much additional work has to be done in this field. One of the things that we are looking into is the establishment of a computer model to determine safe separation of end items and in-process explosive materials without excessive amount of tests. This program, if successful, will reduce the confirmatory type tests to a minimum.

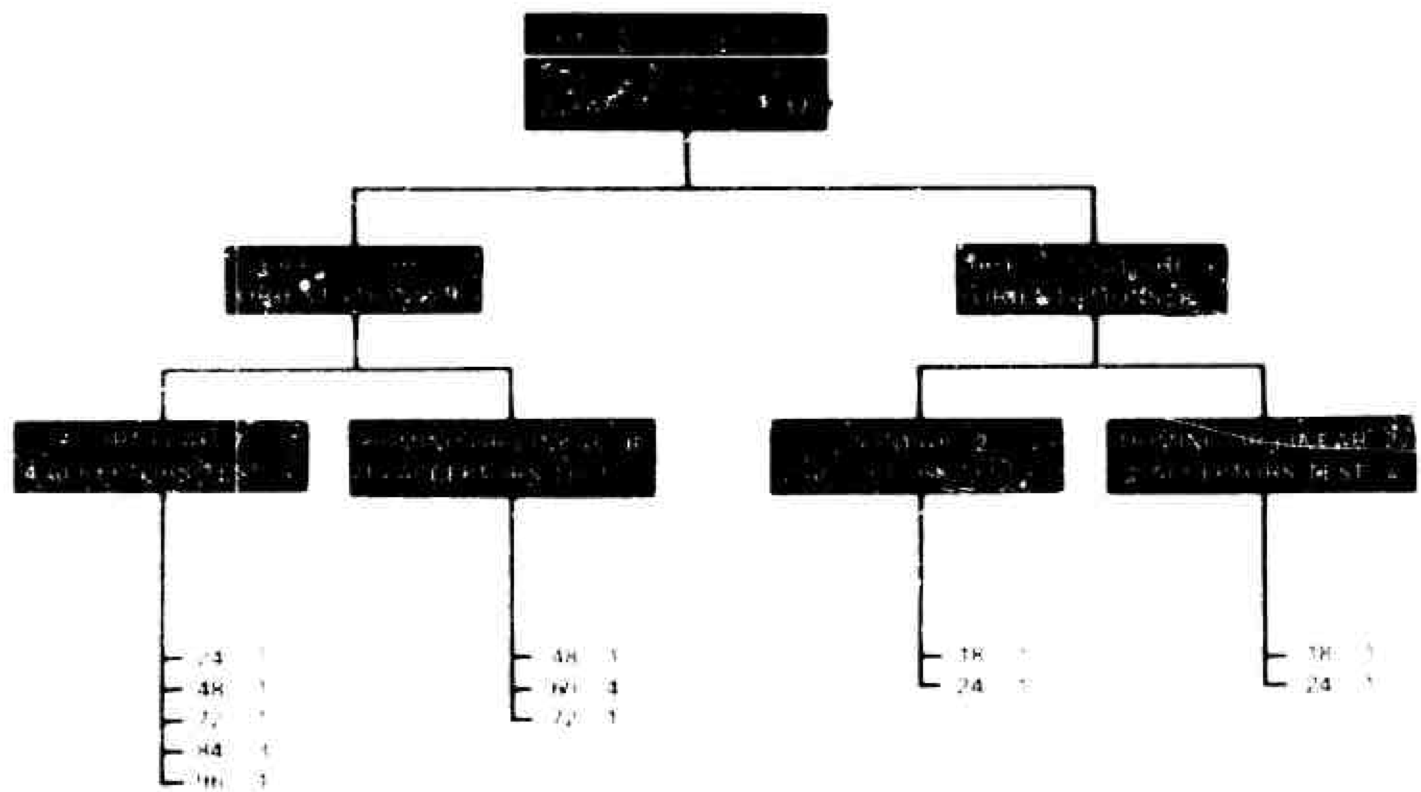
It is expected that results of this program which eventually will become a supplement to our present safety manual (AMCR385-100) will reduce cost and increase safety of LAP and explosive manufacturing facilities.

TABLE 1

ESTABLISHMENT OF SAFE SEPARATION DISTANCE FOR AMMO ITEMS AND IN-PROCESS EXPLOSIVES

- ESTABLISH SAFE SEPARATION DISTANCE AND/OR SHIELDING FOR 155MM COMP B LOADED PROJECTILE ON CONVEYOR
- ESTABLISH SAFE SEPARATION DISTANCE AND/OR SHIELDING FOR 2.75" ROCKETS
- ESTABLISH SAFE SEPARATION DISTANCE AND/OR SHIELDING FOR 81MM SHELL
- ESTABLISH SAFE SEPARATION DISTANCE FOR 55 LBS TNT LOADED BOXES ON CONVEYOR
- ESTABLISH SAFE SEPARATION DISTANCE FOR 60 LBS COMP B LOADED BOXES ON CONVEYOR
- ESTABLISH SAFE SEPARATION DISTANCE FOR M18 MINES, C_4BLOCKS AND C_4BUCKETS

TABLE 2
SUMMARY—155MM SEPARATION DISTANCE
PART 1



(a) THE NUMBERS IN BRACKETS RE 'ER TO THE NUMBER OF TESTS CONDUCTED FOR THAT GROUP OR ITEM

(b) THE NUMBERS SHOWN BELOW IN PARENTHESIS REFER TO THE CLEAR SEPARATION DISTANCE IN INCHES BETWEEN THE DONOR SHELL AND ANY ONE ACCEPTOR SHELL

TABLE 3

PERFORMANCE OF DIFFERENT SHIELDS FOR 18-INCH CLEAR SEPARATION DISTANCE

TYPE OF SHIELD	THICKNESS OR DIA OF SHIELD IN	WT OF THE SHIELD LBS	AREA OF THE SHIELD FACING THE DONOR SQ IN	AVG DISPLACEMENT OF ACCEPTOR YARDS	REMARKS
ALUM PLATE*	1	22	225	72	NO PROPAGATION
STEEL PLATE*	½	32	225	120	NO PROPAGATION
ALUM ROD	2	7.4	48	13	NO PROPAGATION
ALUM ROD	3½	19.2	84	53	NO PROPAGATION
STEEL ROD	2	21.4	48	31	NO PROPAGATION
2 STEEL RODS	2	21.4	48	27	NO PROPAGATION
ALUM PIPE	3½	7.1	84	35	NO PROPAGATION
STEEL PIPE	3½	20.5	84	40	NO PROPAGATION

* CONFIRMATORY TESTS PERFORMED FOR THIS TYPE OF SHIELD

TABLE 4

SUMMARY OF PROPAGATION TESTS FOR 55 POUND BOXES OF TNT

NO OF TESTS	DIST FROM DONOR (FT)	NO OF ACCEPT	TEST SET-UP	REMARKS
1	4	4	BOXES ON WOODSTOOL	1 BOX DETONATED, 3 BURNED
4	6	16	BOXES ON WOODSTOOL	16 BOXES BURNED
1	6	2	BOXES ON CONVEYOR	1 BOX BURNED, 1 DETONATED
2	8	10	BOXES ON WOODSTOOL	3 BOXES BURNED, 7 NA
7	8	14	BOXES ON CONVEYOR	2 BOXES BURNED, 12 NA
3	8	6	BOXES ON CONVEYOR WITH COVER	5 BOXES BURNED, 1 DETONATED (LO)
2	10	12	BOXES ON WOODSTOOL	1 BOX BURNED, 11 NA

NA= NO ACTION

TABLE 4

SUMMARY OF PROPAGATION TESTS FOR 55 POUND BOXES OF TNT (CONT)

NO OF TESTS	DIST FROM DONOR (FT)	NO OF ACCEPT	TEST SET-UP	REMARKS
3	10	6	BOXES ON CONVEYOR	6 BOXES NA
1	10	2	BOXES ON CONVEYOR WITH COVER	2 BOXES BURNED
7	12	42	BOXES ON WOODSTOOL	1 BOX BURNED, 41 NA
3	12	6	BOXES ON CONVEYOR WITH COVER	6 BOXES BURNED
2	14	4	BOXES ON CONVEYOR WITH COVER	3 BOXES BURNED, 1 NA
8	16	16	BOXES ON CONVEYOR WITH COVER	2 BOXES BURNED, 14 NA
2	18	4	BOXES ON CONVEYOR WITH COVER	4 BOXES NA

NA = NO ACTION

FIG. 1 155MM SHELL SEPARATION TESTS
TEST SET UP

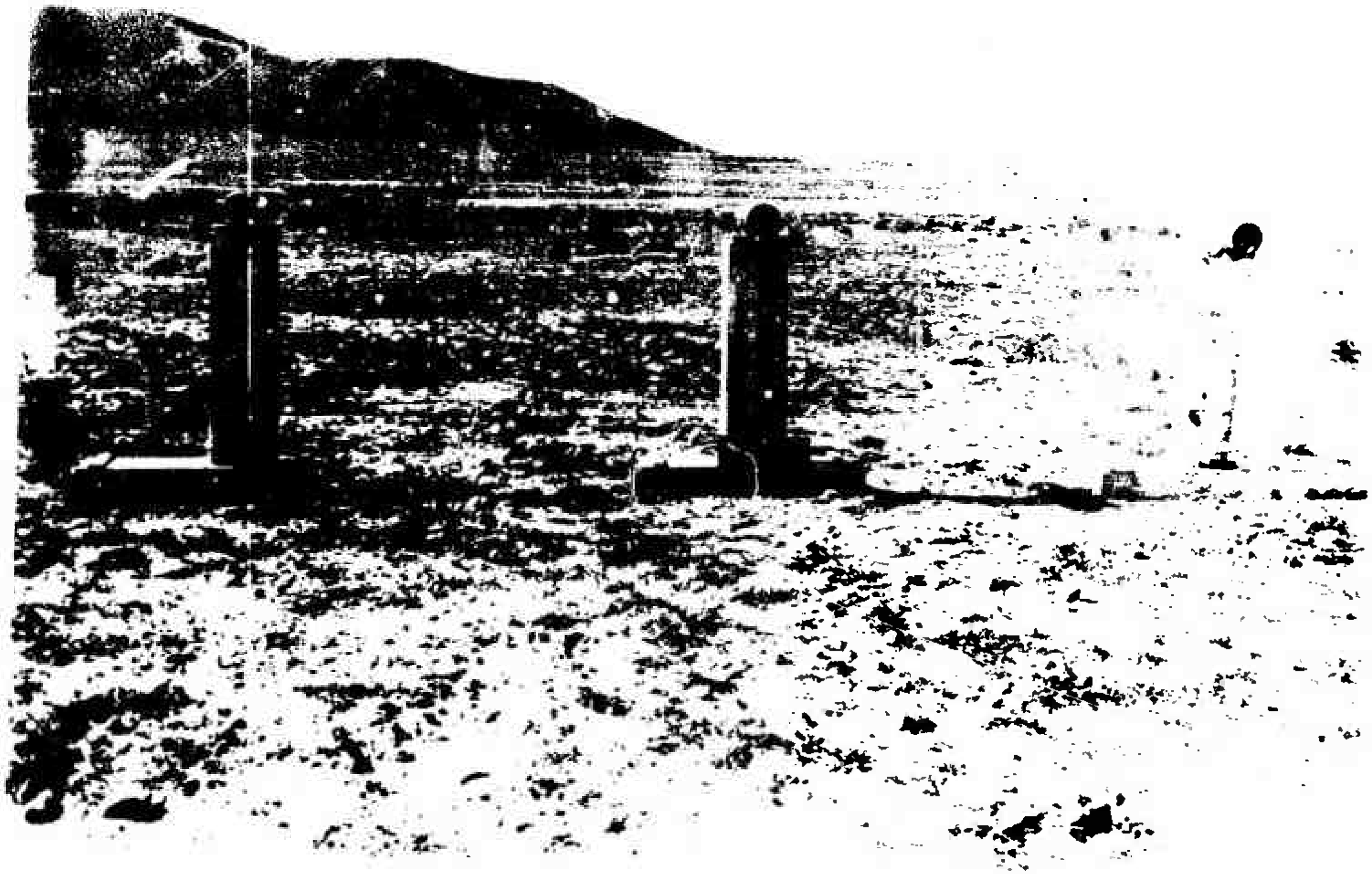


FIG. 2 155MM SHELL SEPARATION TESTS
TEST SET-UP


TEST 12
HORZ

FIG. 5 155MM SHELL-SHIELDING TESTS
TEST SET-UP

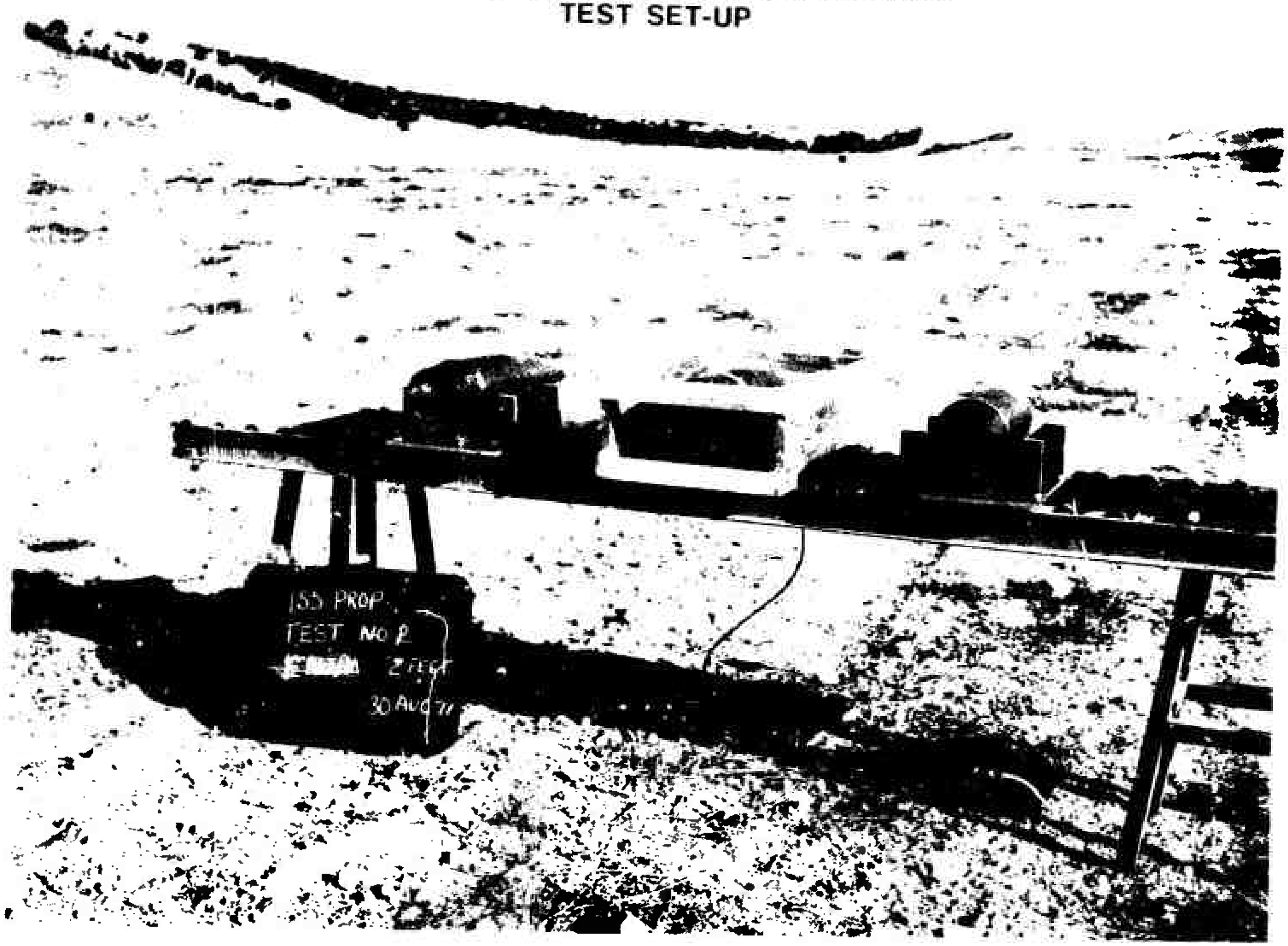


FIG. 6 155MM SHELL-SHIELDING TESTS
TEST SET-UP

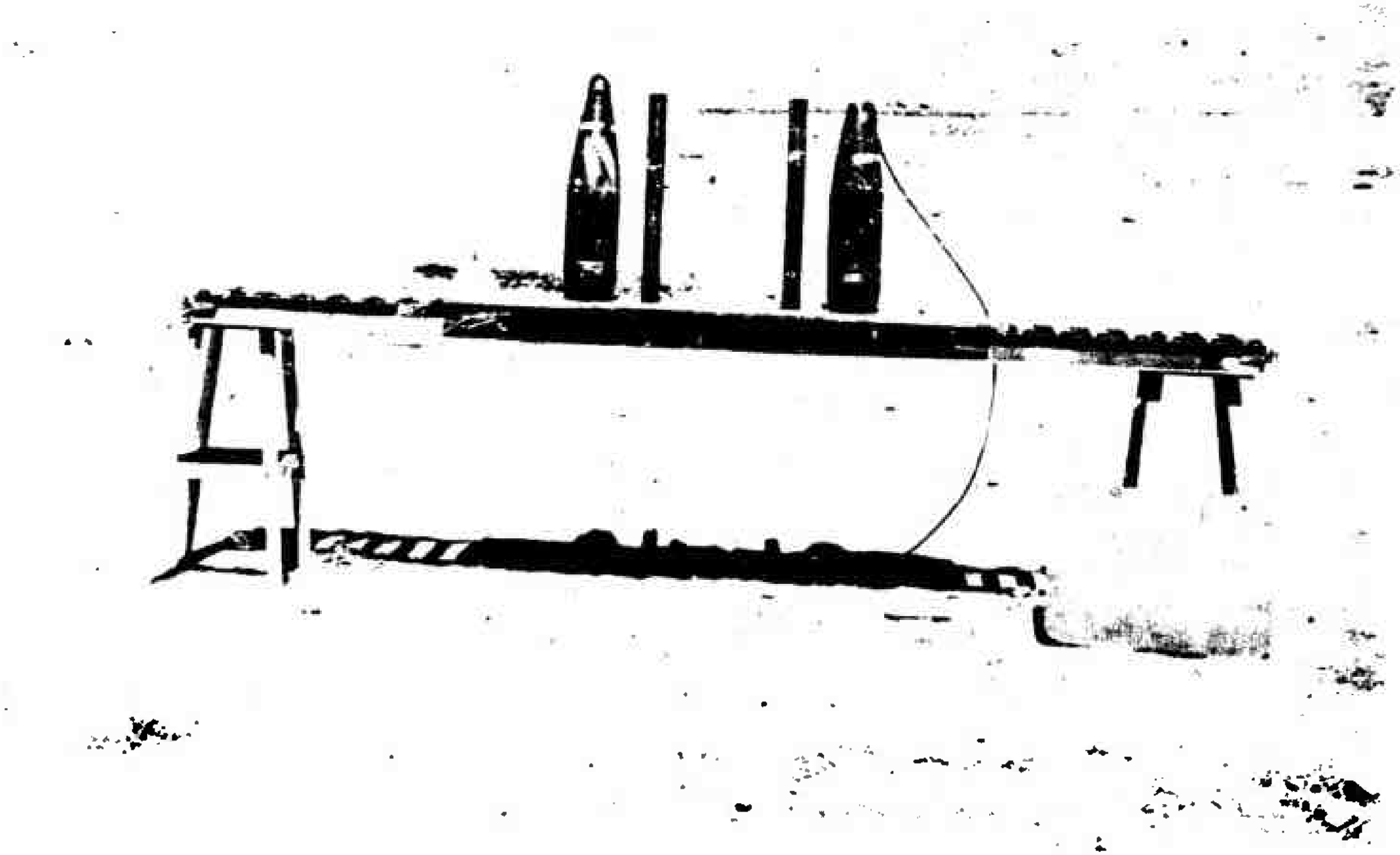


FIG 7 155MM SAFE SEPARATION TESTS (3½" PIPE)

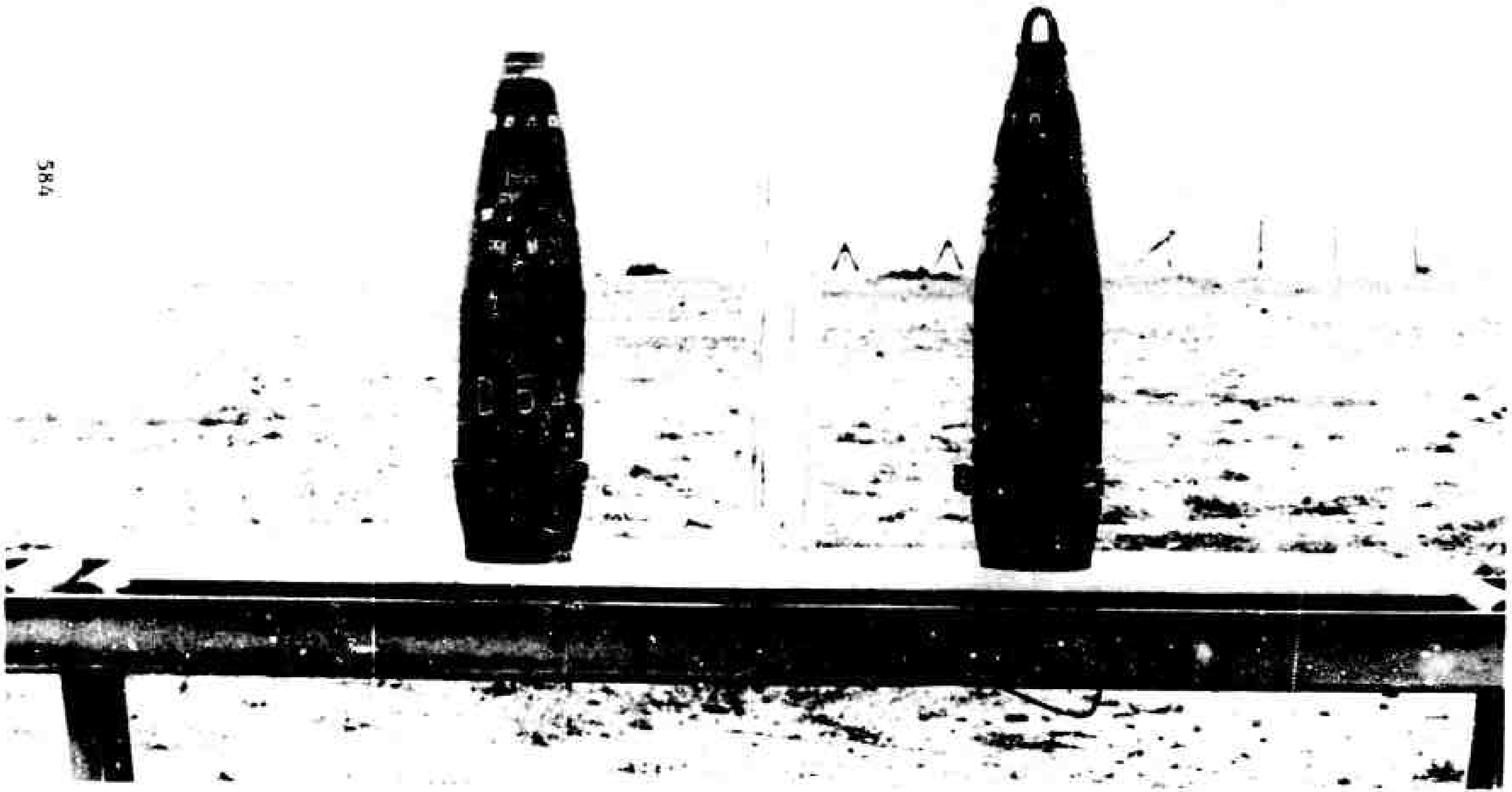


FIG. 8
RELATIONSHIP BETWEEN PROBABILITY OF PROPAGATION AND NUMBER OF TESTS FOR A GIVEN CONFIDENCE LEVEL

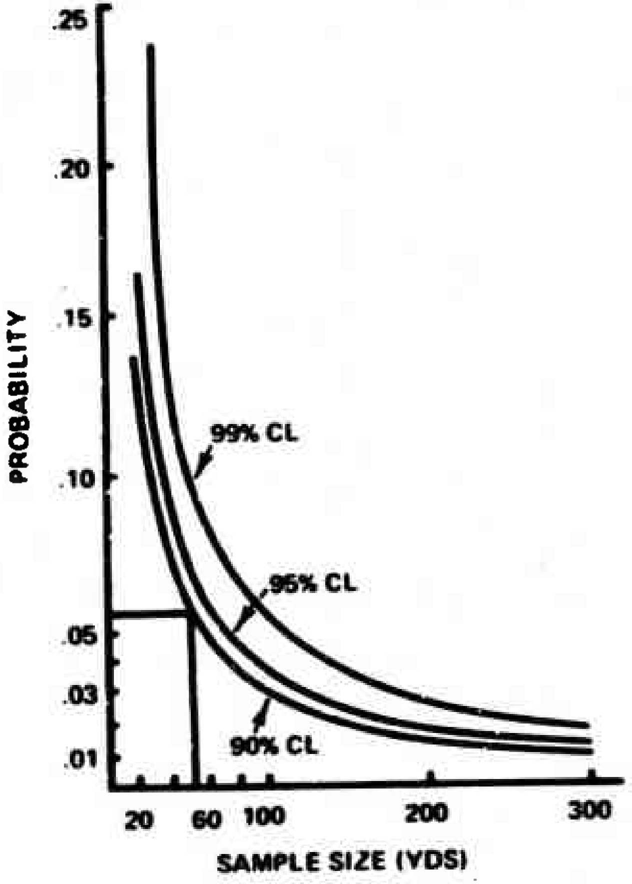


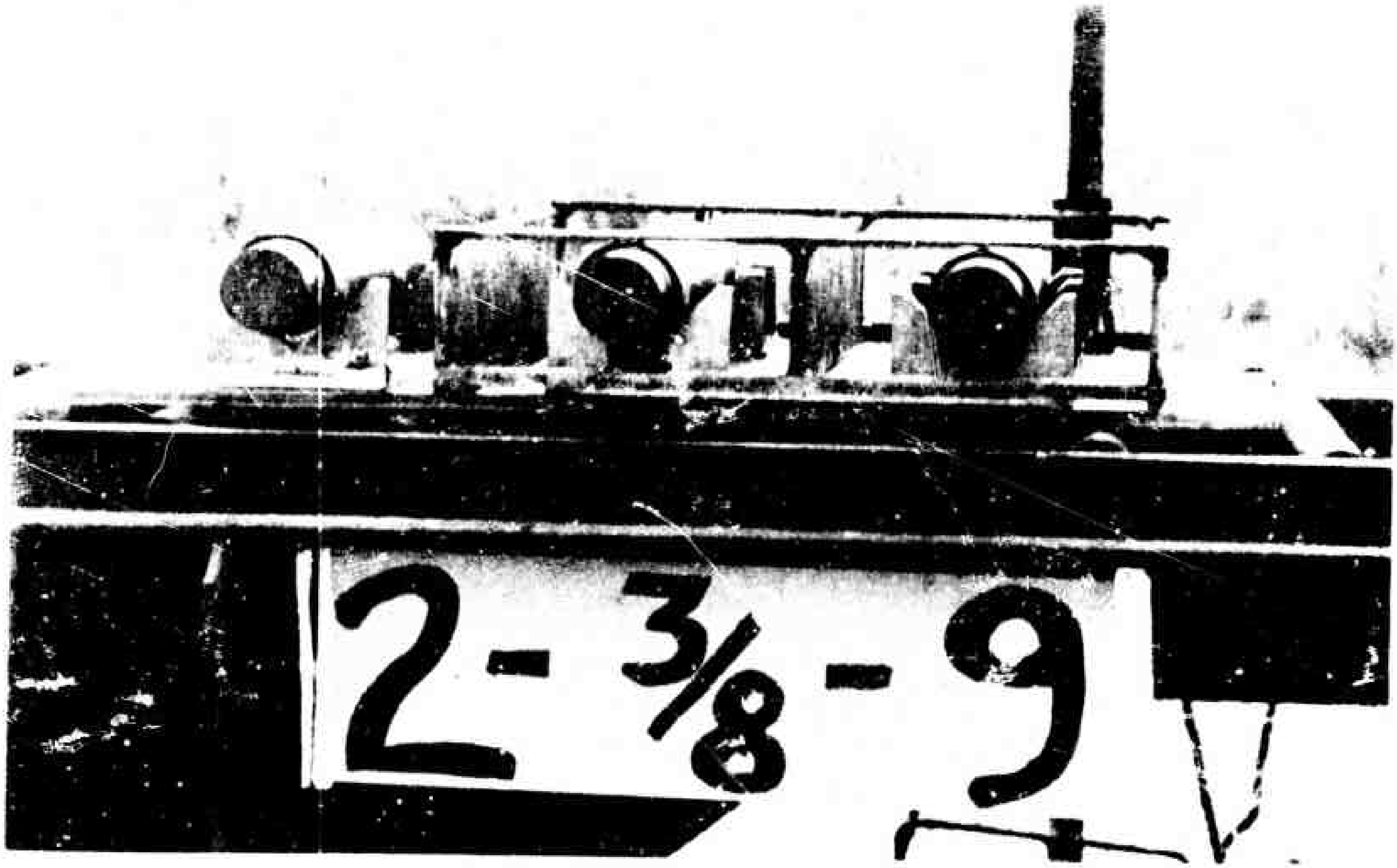
FIG. 9 55LBS. BOXES PROPAGATION TEST
TEST SET-UP

FIG. 10 55LBS. BOXES PROPAGATION TESTS
TEST SET-UP

FIG. 11 55LBS. TNT BOXES PROPAGATION TESTS
TEST SET-UP

FIG 12 2.75" ROCKET WARHEAD SAFE SEPARATION TESTS
(2" O D × ½" THK STL PIPE)

FIG 13 2.75" ROCKET WARHEAD SAFE SEPARATION TESTS
(3/8" THK STL PLT AT 9" SPACING)



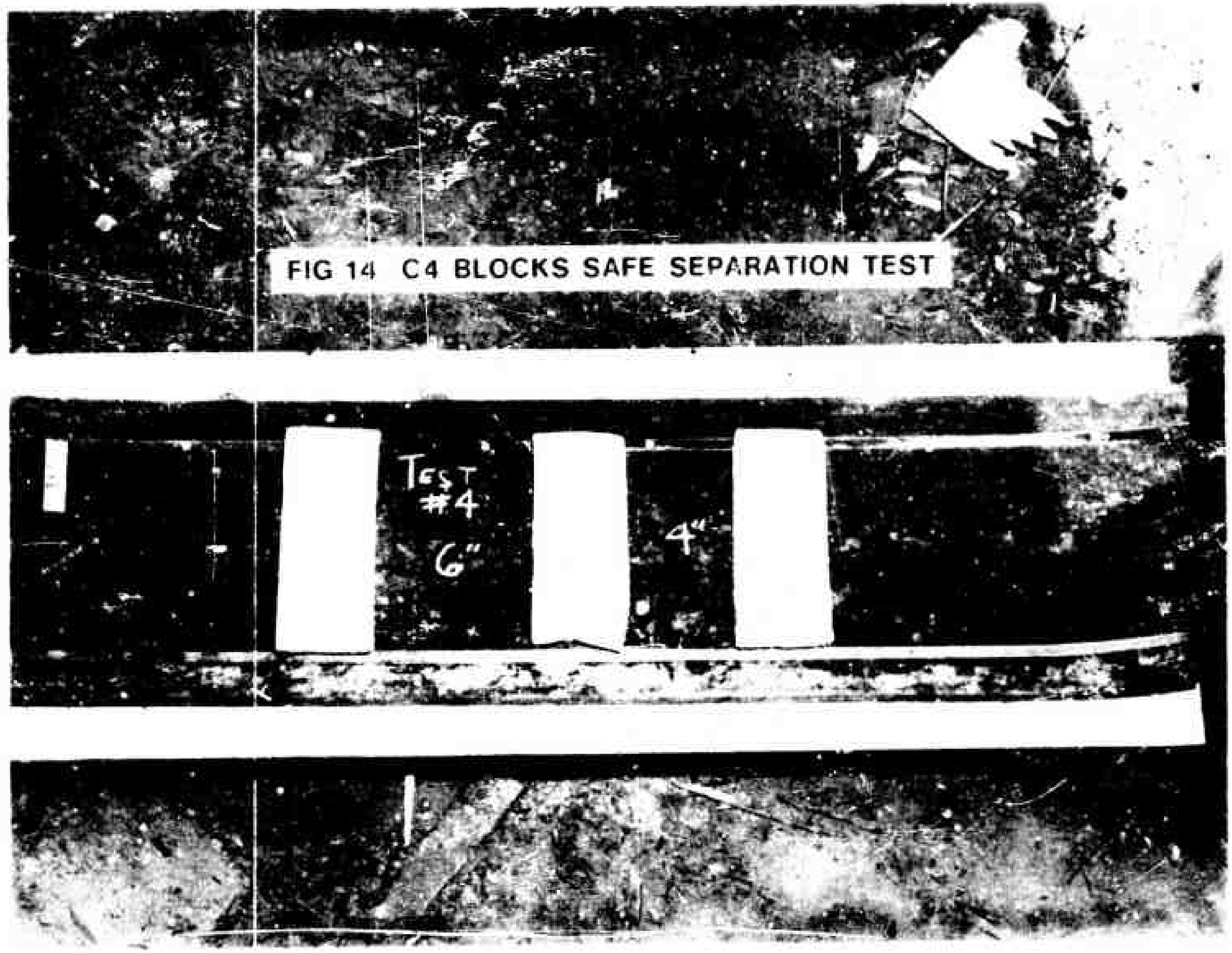


FIG 14 C4 BLOCKS SAFE SEPARATION TEST

Results of Some Recent Flying Plate Impact Tests on Two Operational Solid Propellants

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ABSTRACT

Threshold conditions for ignition or initiation of solid propellant rocket motors upon impact are of concern to all persons responsible for handling, transporting or launching these motors. The Thiokol/Hercules Joint Venture, as a part of their program to develop rocket motors for the Poseidon missile, determined the major variables affecting propellant reactivity during impact.

The test selected for this program is the flying plate impact test. Prior work had determined that this test can duplicate a spectrum of missile impact velocities and collision duration times. Propellant samples were 3" x 3" cylinders. Steel plate weights were varied from 6 to 56 lbm.

A 16 mm movie was shown at the meeting, summarizing test results obtained for both first stage (a composite propellant) and second stage (a composite modified double base propellant) Poseidon rocket motors.

The most important result from these tests is that ignition threshold velocities are well within the range for transportation and handling accidents. The heavier plates resulted in longer duration impacts and caused ignition to occur at velocities as low as 74 ft/sec, as shown in the attached two figures.

The results are not sufficiently precise to establish whether total energy delivered to the sample, or the rate at which this energy is delivered, is the determining mechanism.

No detonations were observed for either propellant, at the relatively low velocities of this study.

Firebrands (flaming fragments of propellant propelled outward from the ignition or explosion) were always evident for the tested composite propellant (when ignition occurred). They were occasionally observed also for the composite modified double base propellant. It is not clear whether these two propellants differ only in degree of firebranding, or whether the higher deflagration pressure (pressure below which the propellant will not sustain combustion) for this particular composite modified double base propellant prevented combustion of the fragments. It would likewise be inappropriate to generalize to say that all composite propellants exhibit firebranding.

Work is in progress to determine the effect of propellant geometric variables and the effect of aging on propellant impact sensitivity.

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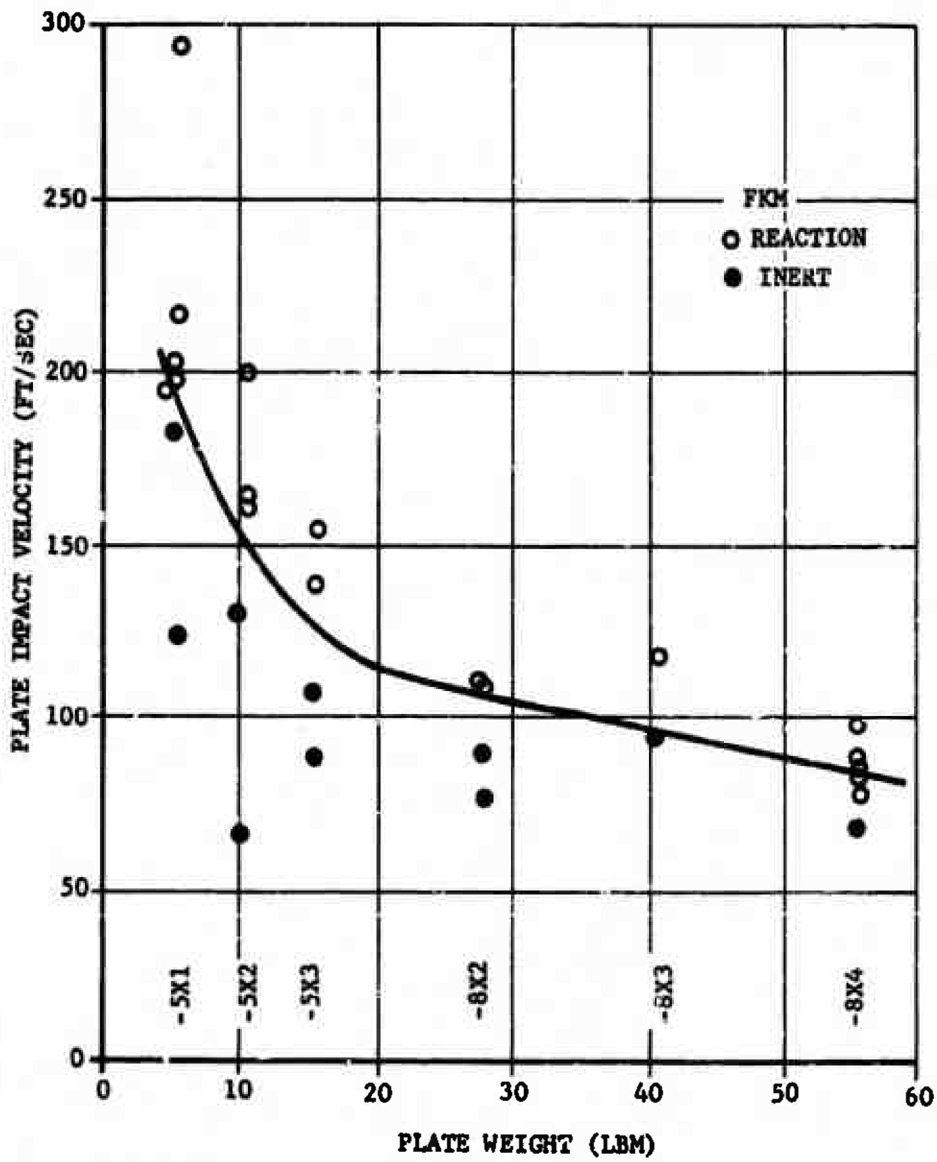

Figure 1. Initiation Velocity of a Composite Modified Double Base Propellant vs. Plate Weight

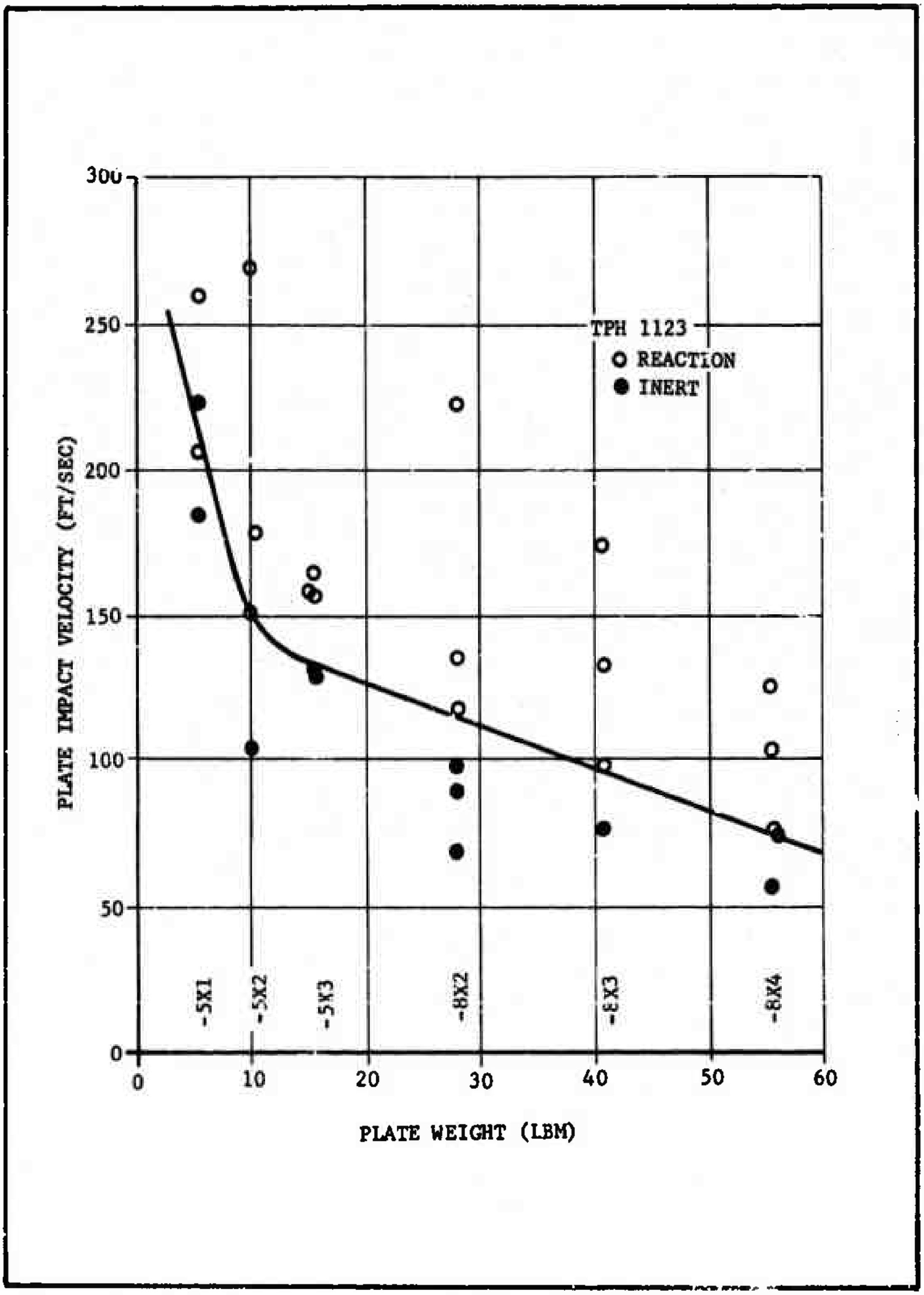

Figure 2. Initiation Velocity of a Composite Propellant vs. Plate Weight

CONDUCTIVE AND "ANTI-STATIC" PLASTIC

KNOW THE DIFFERENCE

"IT COULD SAVE A LIFE"

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CUSTOM MATERIALS, INC.
CHELMSFORD, MASSACHUSETTS

(Much confusion and mystery still exists concerning the differences between conductive and "anti-static" plastic materials, their properties and how they are measured. This article explains their differences and shows which materials parameters are important for various applications and how these parameters are measured).

INTRODUCTION

Conductive plastic film materials are receiving more widespread use as industrial and commercial users are becoming increasingly aware of the extreme dangers involved in using standard plastic materials in hazardous environments. In areas, for example, where spark discharges can set off explosions, ordinary plastic films are being banned.(1), (2). Hospital operating rooms using explosive anesthesias are now requiring conductive operating table covers, sheeting, hamper liners and kick-bucket liners. Munitions and chemical plants are requiring conductive containers and bags along with special grounding techniques to reduce hazards. Areas where dust may also produce an explosive atmosphere are also using conductive instead of the usual plastic materials.

Conductive materials are also being employed in areas where sensitive electrical and electronic equipment is being fabricated or tested. In these cases, currents, caused by static electricity discharges through the electronic devices can cause damage or complete destruction. By producing a conductive work station and using grounding techniques, these hazards are eliminated.

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The mechanism for generating static electricity is quite simple,(3). A charge of static electricity can be built up on a plastic sheet, clothing or any other object by rubbing against another material. This rubbing can be, for example, a leather sole scuffing a rug, articles of clothing rubbing together, or even air from a heating duct being blown across an object. This static charge is due to electrons which are removed from one object and deposited on another during the rubbing process. If the object in question is a metal, or made of a conducting material, the electrons can move about freely. If any part of the object is touched to a grounded body, such as the earth, a water or gas pipe, electrical conduits, etc., the charge will run off harmlessly to ground. If, however, the object is an insulator or an insulating film, the electrons are not free to move but are "trapped" or "bound" to the material at the spot where they are produced. These bound electrons or static charges thus remain on the film even if many parts of the film are grounded. The insulating film, therefore, is a constant threat as a cause of a static discharge spark.

Because plastic insulating films can retain a static charge, they should never be used in hazardous environments. These films should be replaced with conductive plastic materials. So called "anti-static" plastics are also finding a market as a substitute for insulating plastics. Because these plastics are not safe under all conditions, as will be detailed in the following, they are not recommended for use in hazardous environments, (4).

Conductive Films. Conductive films are usually plastics, such as polyethylene, which have been compounded with a conducting material, such as carbon or a metallic powder. While these films are not as conductive as metal, they are

still "good" conductors, and remain "good" conductors despite changes in environmental parameters, such as humidity, storage time, light exposure, etc. Conductive films are considered as bulk, (volume), conductors, since the conductive loading material is distributed throughout the film allowing the electrons to flow throughout the bulk of the material.

"Anti-Static" Films. "Anti-static" films, on the other hand, are also plastics, but those which have been loaded with a "detergent" type material. This detergent, when exposed to a high humidity environment acts as a hygroscopic agent which picks up water molecules and provides a conductive path along the surface of the film. It is the conductivity of these water molecules which allows the electrons to bleed off, reducing the static discharge hazard. Due to the surface conduction process, these materials are classified as surface conductors.

Unfortunately, since the conducting path for these "anti-static" materials is only a microscopic layer at the surface of the film, the conductive properties of the materials vary radically with environmental conditions.

In order to understand in detail the differences in performance of conductive and "anti-static" films, one must understand what electrical parameters are important in describing these films, and how these parameters are measured. Basically, two distinct and separate types of parameters, and thus measurements, have become common in describing these films. The first set of these concerns the basic electrical parameters which indicate how easily the electrons can flow in the material, or how well the material conducts electricity. The parameter of particular interest is the

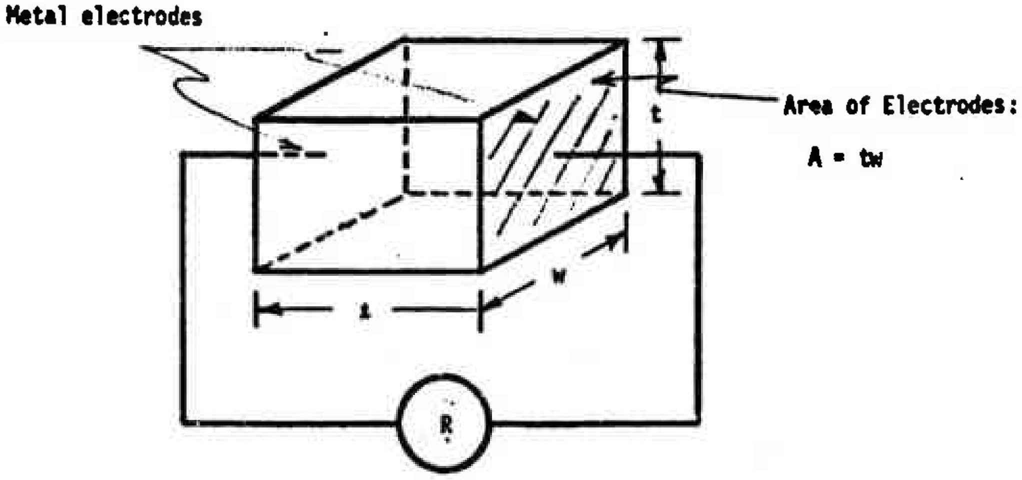
electrical conductivity of the film or its inverse, electrical resistivity. A second set of parameters describes how rapidly a static charge can be dissipated or bled from a given film. These parameters can be measured separately as will be described later.

RESISTANCE, CONDUCTANCE, RESISTIVITY AND CONDUCTIVITY

Most elementary text books give good explanations of the concepts of resistance, conductance, resistivity and conductivity. For our purposes, it is sufficient to use resistance as the basic concept and explain the other parameters in terms of this resistance. Ohm's Law states that $I = \frac{V}{R}$ so that the resistance R relates how much current, I, will flow in an electric circuit if a given voltage V is applied across it. Note the fact that the higher the resistance the lower the current flow will be for a given voltage. Conductance, G, is defined as the inverse of resistance so that Ohm's Law becomes $I = GV$.

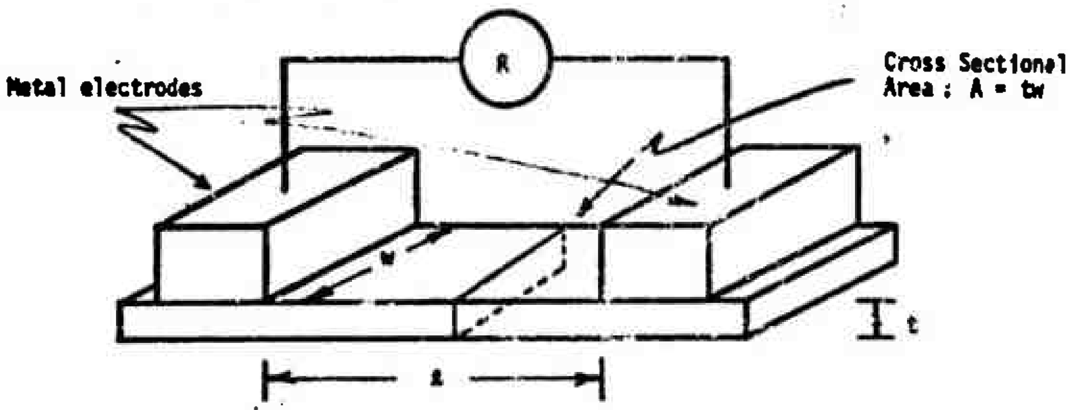
The volume resistivity, ρ_V, of a material is an intrinsic property of the material and does not depend upon the geometry of the sample. The resistance R, of a material is given in terms of the volume resistivity, ρ_V, as shown in Figure 1a and 1b for both a bulk sample and a thin film.

The surface resistivity ρ_S of a material is commonly used to describe materials in the form of a film or a thin sheet. Its value is usually defined as being equal to the resistance measured between two electrodes of a given width separated from each other by a distance equal to the width. Thus, referring to Figure 1b, if $\ell = w$ the measured resistance R is given by:



$$R = \frac{\rho_v \ell}{A} = \frac{\rho_v \ell}{t\,w}$$

FIGURE 1a. VOLUME RESISTIVITY MEASUREMENT USING A BULK SAMPLE



$$R = \frac{\rho_v \ell}{A} = \frac{\rho_v \ell}{t\,w} = \frac{\rho_s \ell}{w}$$

$$\text{Definition: } \rho_s \equiv \frac{\rho_v}{t}$$

FIGURE 1b. VOLUME AND SURFACE RESISTIVITY USING THIN FILM SAMPLE

$R = \frac{\rho_V \ell}{A} = \frac{\rho_V \ell}{tw} = \frac{\rho_V}{t} = \rho_S$. Note here that ρ_S is defined in terms of the volume resistivity ρ_V. The value of ρ_V is given in ohm-cm while ρ_S is given in ohms/square. This terminology is used since the value of resistance measured between the two electrodes is the same no matter what the size of the electrodes, as long as the measured area of the sample remains a square, i.e., $\ell = w$.

For "anti-static" materials, the conduction process takes place only along the surface of the material, and the surface resistivity usually has no connection with the volume resistivity.

MEASUREMENT OF CONDUCTIVE FILM RESISTIVITIES.

By using the measuring circuit and equation of Figure 1a or 1b, it is theoretically possible to measure and calculate film resistivities, However, in actual practice, this technique rarely works, since major errors are intoduced from two sources:

(a) If the sample to be measured is not the same width as the electrodes, using the technique of Figure 1b, the measured value of resistance will be erroneously low due to the shunting effect of the material outside of the electrodes.

(b) Virtually all conductive materials exhibit an interface resistance which occurs at the interface between the metal electrode and the conductive plastic. This interface resistance may be equal to or more than the resistance which one is trying to measure. The interface resistance is pressure sensitive and exists even in the case of painted or printed-on electrodes. Interface resistance can cause errors using either technique shown in Figure 1a or 1b.

In order to eliminate the first of the above problems, one needs only to cut the test sample to the same width as the electrode. In order to eliminate

the effect of the interface resistance, measurement must be made by a method, such as ASTM Standard 991-68 or equivalent.

ASTM STANDARD-991-68. This standard, entitled "Volume Resistivity of Electrically Conductive and Anti-Static Elastomers" is published by the American Society for Testing and Materials (5). It is an extremely accurate technique for the determination of volume resistivity ρ_V in the presence of an interface resistance. The technique assumes that there is no appreciable surface conduction mechanism so that all of the current flows through the bulk of the film. The measurement is made by passing a known current, I, through the film to be measured by means of two electrodes at the ends of the sample. The current is adjusted to be small, so that no heating of the sample occurs. The resistance of the sample can be determined by measuring the voltage drop, V, between two very accurately spaced knife blade electrodes. If a very high impedance voltmeter is used to measure the voltage drop, negligible current will flow through the voltmeter and thus also through the interface resistance. The voltage drop measured will thus be due solely to the bulk resistivity of the film. The volume resistivity can be calculated as follows:

$$\rho_V = \frac{V}{I} \frac{tw}{d}$$

Where ρ_V is in ohm-cm, V in volts, and I in amps. The thickness t and width w of the sample are given in cm, as well as the electrode spacing d.

SURFACE AND VOLUME RESISTIVITIES OF "ANTI-STATIC" FILMS

As was previously mentioned, "anti-static" films, are surface conducting films, i.e., the electrons move along a thin surface layer and not in the bulk of the film Thus, the two resistivities ρ_S and ρ_V are independent parameters

and are not connected by means of the formula $\rho_v = \rho_s t$, as they are with the conductive plastics. In the case of "anti-static" films, both the surface and volume resistivities are much higher than those of conductive films; in many cases approaching the value of insulators. Both the surface and volume resistivities can be measured, but techniques differing from those used to measure conductive films must be used.

The American Society for Testing and Materials Standard "D.C. Resistance or Conductance of Insulating Materials" No. D-257-66 (5) is usually appropriate for use in measuring the resistivities of "anti-static" materials and films. This Standard actually describes a number of techniques and a number of electrode configurations which can be used. For measuring surface resistivity, a slight procedure modification of this Standard is necessary and is described following.

The ASTM three electrode configuration is a so-called guarded electrode system. This guarded electrode technique is used to eliminate errors caused by shunt current paths outside the measuring electrodes, and is described in detail in Reference (6).

Volume Resistivity. Measurements can be made directly using the above technique by making a resistance measurement through the thickness of the sample (i.e., the current flows from electrodes placed on either side of the film sample as is shown in Figure 1a). By this means, the measured resistance is as small as possible since the current flows only for a short distance through the thickness of the film, which is usually only a few thousandths of an inch thick. By measuring through the film thickness, the measurement of high resistivity film is made slightly easier since many megohmeters do not read high enough to allow a measurement to be made along the length of the film, as is, for example, shown in Figure 1b.

It should be stressed that the interface resistance has been neglected in this measurement. If the measurement appears to depend upon electrode pressure, one should use painted or silver electrodes as is described in the ASTM Standard, or attempt to use techniques, such as described earlier which eliminate the effect of the interface resistance.

Surface Resistivity. Direct measurements cannot be made using the ASTM technique (Section 4.6 of Reference 3) since the resistance measured is usually a parallel combination of the resistance along the surface and the bulk resistance of the interior of the film. If one, however, first measures the volume resistivity ρ_V, one can calculate a value for the bulk resistance in the film. The contribution from this resistance can then be subtracted from the measured resistance, thus allowing ρ_s to be determined. If the calculated value of the bulk resistance is at least twice as great as the measured resistance, one can expect a reasonably accurate value for the surface resistivity ρ_s.

Summary. Resistivities and their measurements for both conductive, and "anti-static" films have been described and their measuring techniques outlined. It has been seen that conductive plastics have resistivities only a few orders of magnitude higher than metal films or foils, while "anti-static" materials have resistivities only a few orders of magnitude lower than insulative films. A comparison of the properties of conductive and "anti-static" films with insulative films is shown in Table I. One can thus conclude that conductive plastics act very much like metals in their ability to provide protection against static build up; giving guaranteed protection with little change in their properties with environmental conditions. "Anti-static" materials on the other hand when exposed to changes in environmental conditions can change from surface conducting films to films with completely insulating characteristics.

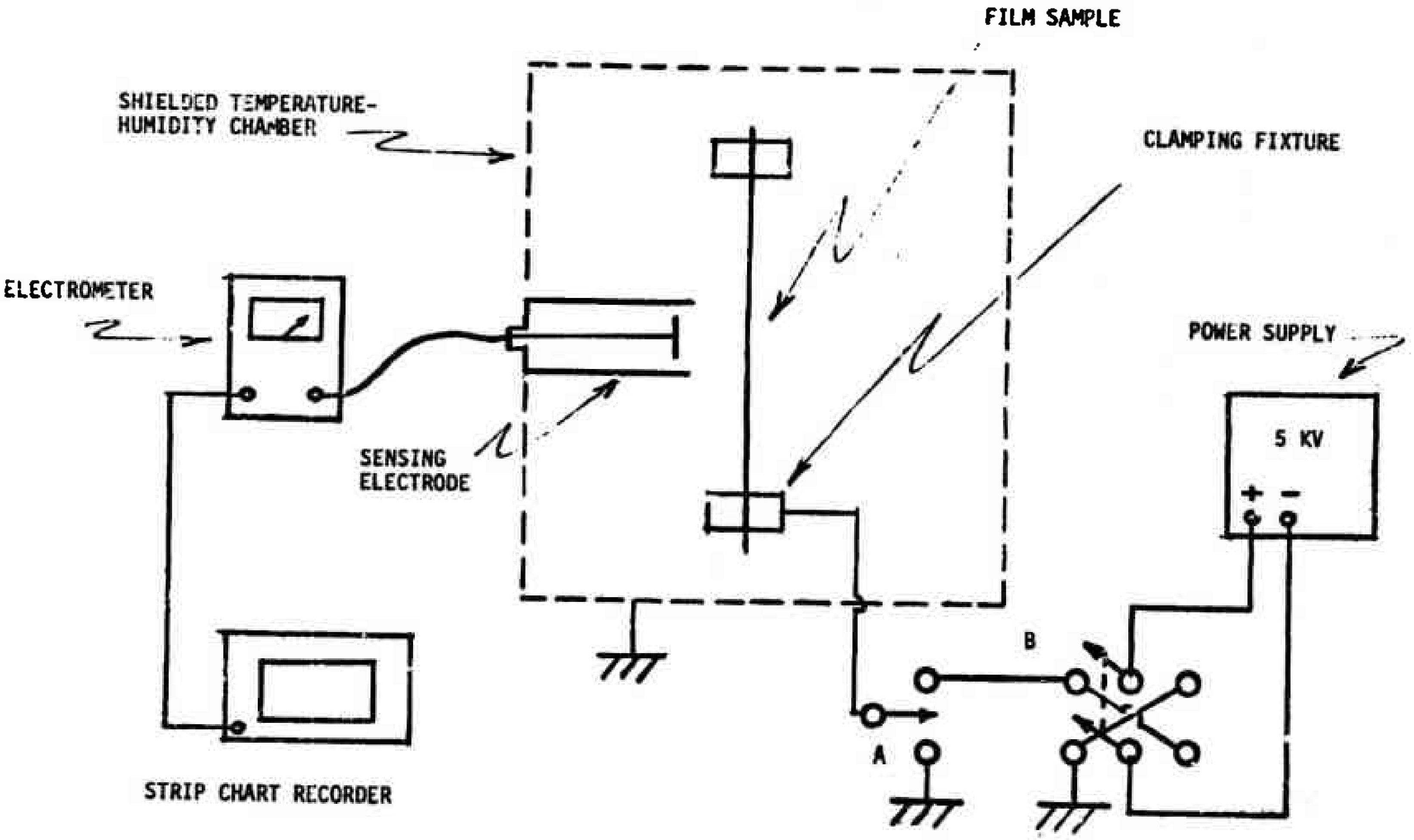


FIGURE 2. SCHEMATIC OF: STATIC BLEED-OFF TEST EQUIPMENT

This behavior can also be observed by making measurements of the "anti-static" parameters of the materials directly. A description of the important "anti-static" properties and parameters, along with their measuring techniques, are presented following.

A considerably more detailed analysis of the measuring techniques for conductive and "anti-static" films is given in Reference 7.

STATIC BLEED-OFF MEASUREMENTS.

The technique most often used today for measuring "anti-static" properties is one of placing a charge on a test specimen and measuring the time required for the film to bleed off or discharge from its maximum charged value. The speed of discharge is an inherent function of the film conductivity and environmental conditions and is a direct measure of the films effectiveness in preventing static hazards; the shorter the discharge time, the more effective the protection.

An example of a measurement technique of the discharge type has been developed by the Aero Materials Dept., Naval Air Systems Command. This technique has been adopted by the U. S. Government as Fed. Test Method Std. No. 101B, Method 4046 (8). In a slightly modified form, it is known as NFPA 56A, "Standard for the Use of Inhalation Anesthetics" (9).

FEDERAL TEST METHOD STANDARD NO. 101B.

The equipment used for this test is illustrated in Figure 2 and shown by photograph in Figure 3. As can be seen, a fixture clamps a sample on the ends by means of metal electrodes. These electrodes are connected to a switch (A), which allows the film to be connected to a power supply (usually

5 kV.) for charging, or to ground for discharging. The power supply is connected to a polarity reversing switch (B) so that a positive or negative potential may be applied to the film. Facing the center of the film is a charge sensing electrode, which is connected to a sensitive, high impedance electrometer. The output of the electrometer is connected to a strip chart recorded, so the charge buildup and decay can be recorded as a function of time. Measurement is made of the time for the sample to discharge to 10% of its original value.

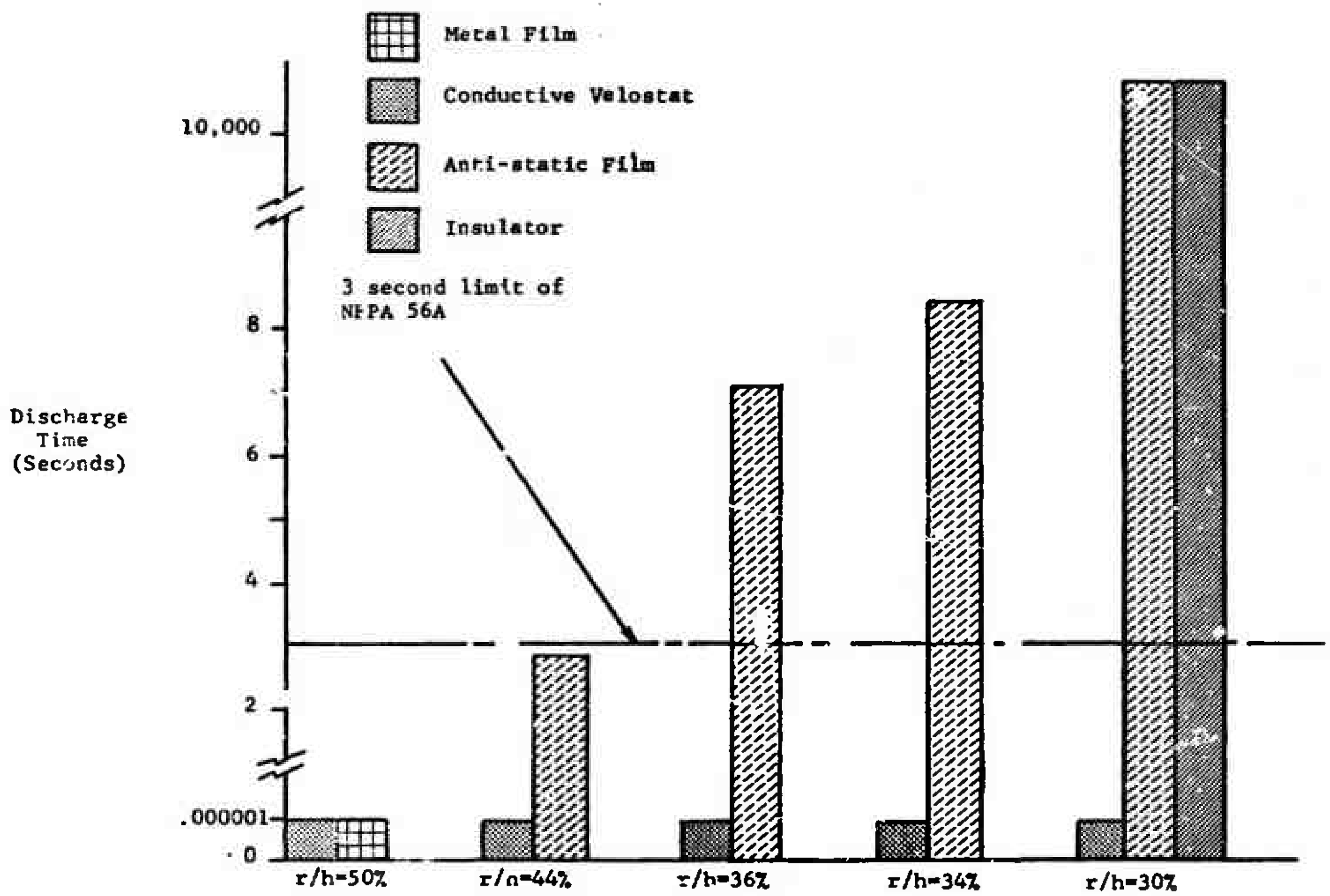
NFPA Standard 56A.

This Standard applies specifically to materials used in areas where explosive anesthesia is used. The portion of the Standard applying to the "anti-static" properties of the materials is Section 25433a. This section is self-explanatory and is quoted below:

METHOD OF CHARGE LEAKAGE TESTING PER NATIONAL FIRE PROTECTION ASSOCIATION STANDARD 56A (Section 25433a).

(a) Antistatic Sheeting and film shall be tested as given in Method 4046 of Federal Test Method Standard #101B except that the material shall be preconditioned for 24 hours at not over 35% ± 5% RH and the tests shall be performed at not over 35% ± 5% RH and 70° ± 3.5° F. After the specimen has received its maximum charge from the application of 5000 volts, the time for the charge to decay to 500 volts (90 percent) shall not exceed 3 seconds.

Examples of typical measurements made on commercially available conductive and "anti-static" films are shown in Figure 4. "A" corresponds to a carbon loaded conductive plastic film showing that it behaves similarly to a metal, "B", in its static bleed-off properties. "C" shows an "anti-static" material, which is within NFPA Specifications at 44% relative humidity. "D" is the same film at 36% relative humidity, while "E" shows the discharge time at 34% relative humidity. Note that this film goes rapidly out of specification limit as the humidity is decreased and at "F" reaches values corresponding to the insulative film "G" at 30% relative humidity.



COMPARISON OF DISCHARGE TIME, CONDUCTIVE AND "ANTI-STATIC" PLASTIC FILMS AT DIFFERENT VALUES OF RELATIVE HUMIDITY (r/h)

FIGURE 4

These latter two films take extremely long times to discharge, on the order of hours, and thus do not appear to discharge at all during the 5 to 15 seconds that is usually taken for a measurement. This type film creates the most hazardous condition for static spark discharge. Figure 4 shows that "anti-static" films can be as dangerous as insulative films.

<u>Effect of Storage Time.</u>

A very important consideration, as will be seen, is how a film recovers its "anti-static" properties after exposure to low humidities.

As one would expect, particularly with films which depend upon surface water adsorption for their properties, the behavior of "anti-static" films depends markedly on the humidity. "Anti-static" films sometimes become insulative when stored at relative humidities of less than 30%. Some "anti-static" films recover rapidly when brought into high humidity (40% or over) environments; others, however, may take hours or even days to recover their "anti-static" properties.

A storage time or "t" parameter has become accepted for the description of "anti-static" films. This parameter describes the length of time that an "anti-static" film takes to meet the 3 second discharge time of NFPA 56A, after having been stored at one relative humidity (usually 20%) and then exposed to a higher relative humidity (usually 40%). For example, $t\,\frac{40\%}{20\%} =$ 380 seconds means it takes 380 seconds for the sample exposed to 40% relative humidity, after being stored at 20% relative humidity, to reach the 3 second specification static bleed off time. Note that other storage and test humidities can be used if they are noted.

It should be stressed that the properties of metallic films and conductive plastics do not change appreciably with humidity. For both of these types of materials, $t\,^{40\%}_{20\%}$ is a small fraction or a second.

As will be seen following, the knowledge of this storage parameter is of extreme importance when "anti-static" material is stored at low humidities, in closed boxes, containers, or in rolls, and <u>must</u> be considered whenever these conditions are encountered.

<u>WHAT THE STANDARDS DON'T TELL YOU.</u>

As one can conclude from the previous discussions, many times the standards and measuring techniques established for "anti-static" materials do not tell a full story on how safe a material may be under actual operating conditions. A typical example of this situation occurs with "anti-static" films being measured per NFPA Standard 56A. Many users of materials which are specified to meet NFPA 56A specifications are under the impression that these materials are safe to use in hazardous environments. In many cases, however, just the opposite may be true; the "anti-static" materials being extremely dangerous. Exactly how these conflicting situations arise is issultrated following:

<u>Behavior of "Anti-Static" Film as a Function of Humidity.</u> Referring to Figure 8, we see that the discharge time varies radically with humidity. Thus, an "anti-static" film may meet the NFPA 56A at its upper limit of 40% relative humidity but be completely ineffective at 33% relative humidity, which is 3% higher then the 30% specification lower limit.

Behavior of "Anti-Static" Films as a Function of Storage. Even if the environment where "anti-static" films are used is carefully controlled for high humidity, it is possible for "anti-static" materials to be dangerous if they have been stored in low humidity areas or in closed containers. Since these materials depend upon the water vapor in the air for their properties, periods of dry-storage may turn them into completely insulative film. This problem has now been recognized and, hence, the "t" parameter mentioned above is a prime specification factor for "anti-static" materials.

Figure 5 shows a comparison of a commercial "anti-static" hospital kick bucket liner and a conductive liner, after having been stored in an environment of 70° F. and 15% relative humidity for three days. The liners were then exposed to an environment of 42% relative humidity. Note that even after an exposure of 160 hours, or more than one full week, the decay time of the "anti-static" liner had only decreased to 66 seconds; still much higher than the 3 second specification requirement. At this point, the humidity was increased to 50%. Only after another three hours did the film finally meet the specification of NFPA Std. 56A.

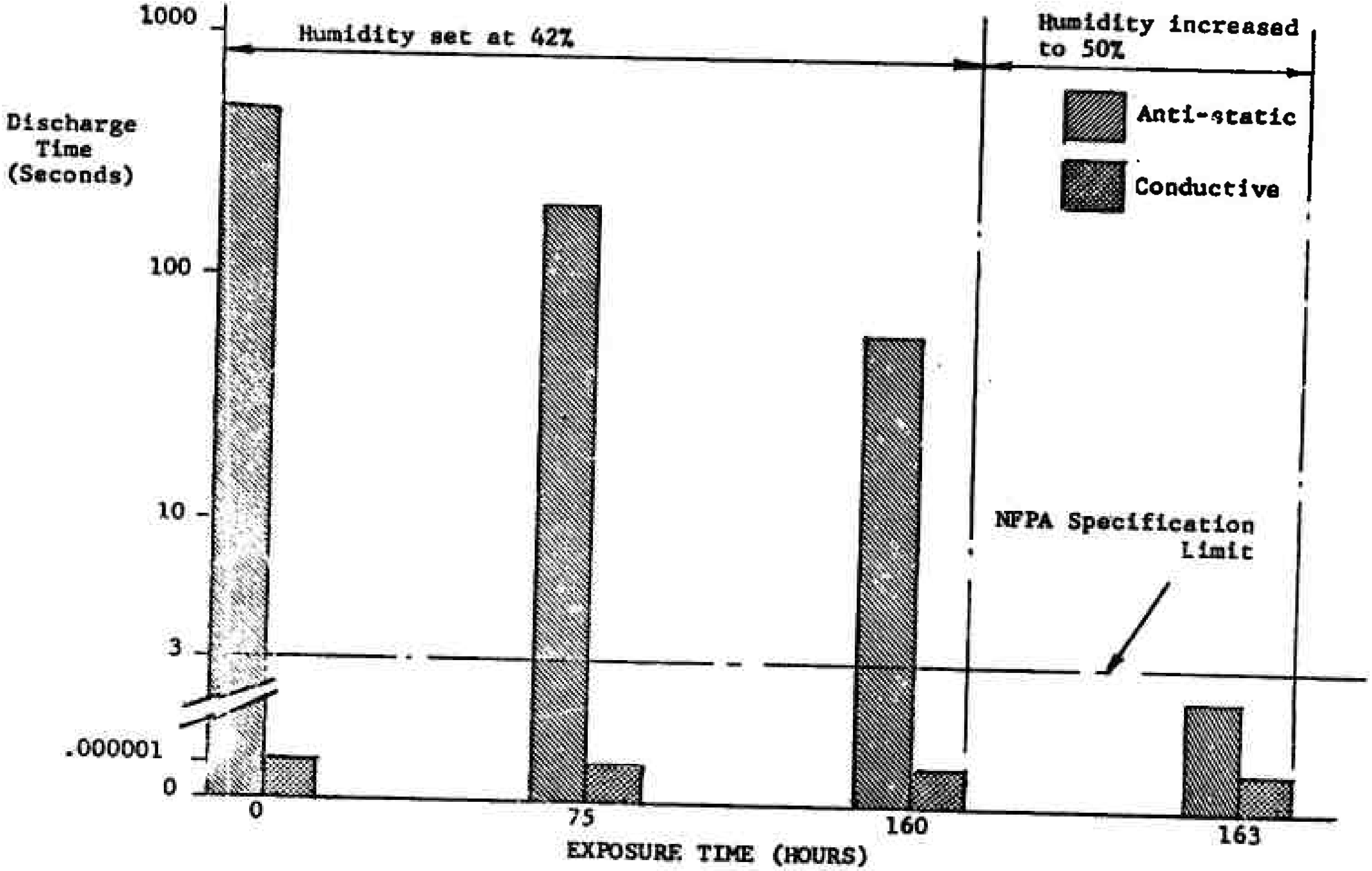
Behavior of "Anti-Static" Films with Age.

Another serious problem exists with "anti-static" materials because of their loss of properties with time. The additives used in these plastics generally leach out over a period of months or years, making the films completely ineffective in preventing charge buildup. Many of the additives are also extremely sensitive to light and rapidly lose their water vapor attracting properties during exposure. Thus, even "anti-static" materials which at first may have acceptable properties, may irreversibly lose these properties with age

Some tests at the Kennedy Space Craft Center, Safety Technology Branch, have compared conductive films with commercially available "anti-static" film. These tests have shown no deterioration with age for conductive films but unacceptable deterioration for the "anti-static" film.

SUMMARY

We have shown how "anti-static" materials depend directly on humidity, aging, and other environmental parameters for their "anti-static" properties, and that these properties can vary radically depending upon their previous history. In order for a user to be safe, the materials used in hazardous or critical areas should be tested just prior to their use and in the environment where they will be used. As this is in many cases undesirable, due to the 5000 volts which is applied to the film, the testing should be performed as close to the use area as is possible without creating hazards. In no case should a user assume that an "anti-static" material is safe just because it meets or is certified to meet the NFPA Std. 56A. If testing equipment is not available, only conductive materials should be used. It should be noted that, in contrast to the complex procedures necessary to assure the safe application of "anti-static" plastics, conductive plastics can be safely and easily measured by simple resistance techniques in the hazardous area, and by non-technical personnel. For example, use of a hospital conductivity tester, or other similar instrument, will easily and reliably tell whether the material is safe. A "green" reading indicating suitable conductivity will assure that the material will meet the bleed-off specification of NFPA 56A under all conditions of storage, relative humidity and time.



COMPARISON OF CONDUCTIVE AND "ANTI-STATIC" FILMS
AFTER REMOVAL FROM STORAGE AT 15% RELATIVE HUMIDITY
AND EXPOSED TO 42% and 50% R.H.
(NOTE DISCHARGE TIMES)

FIGURE 5

TABLE I

COMPARISON OF CONDUCTIVE, "ANTI-STATIC" AND INSULATIVE PLASTIC FILMS

TYPE OF FILM	HOW FABRICATED	VOLUME RESISTIVITY ρ_v	SURFACE RESISTIVITY ρ_s	STATIC DECAY TIME $(\tau_{.1})^{+5\ kV}_{d}$*
CONDUCTIVE FILMS	POLYETHYLENE LOADED WITH CARBON OR METAL POWDER AND EXTRUDED	10^{-1} TO 10^{4} OHM-CM	10 TO 10^{6} OHMS/SQUARE	LESS THAN 1 MICRO-SECOND AT ALL RELATIVE HUMIDITIES
"ANTI-STATIC" FILMS	POLYETHYLENE LOADED OR COATED WITH SUR-FACTANT (USUALLY A DETERGENT)	10^{10} TO 10^{15} OHM-CM	10^{10} TO 10^{15} OHMS/SQUARE	1/2 TO 1000 SECONDS DEPENDING UPON HUMIDITY
INSULATIVE FILMS	USUALLY POLY-ETHYLENE EXTRUDED INTO FILM	GREATER THAN 10^{15} OHM-CM	GREATER THAN 10^{15} OHMS/SQUARE UNLESS CONTAMINATED	GREATER THAN 500 SECONDS

* Symbol indicates measurement made was time for discharge (d) from +5 kV to 10% (.1) of the original value or 500 volts.

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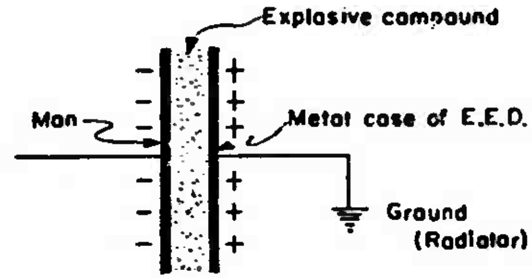
DWG. NO. 1-A

STATIC SPARK HAZARDS

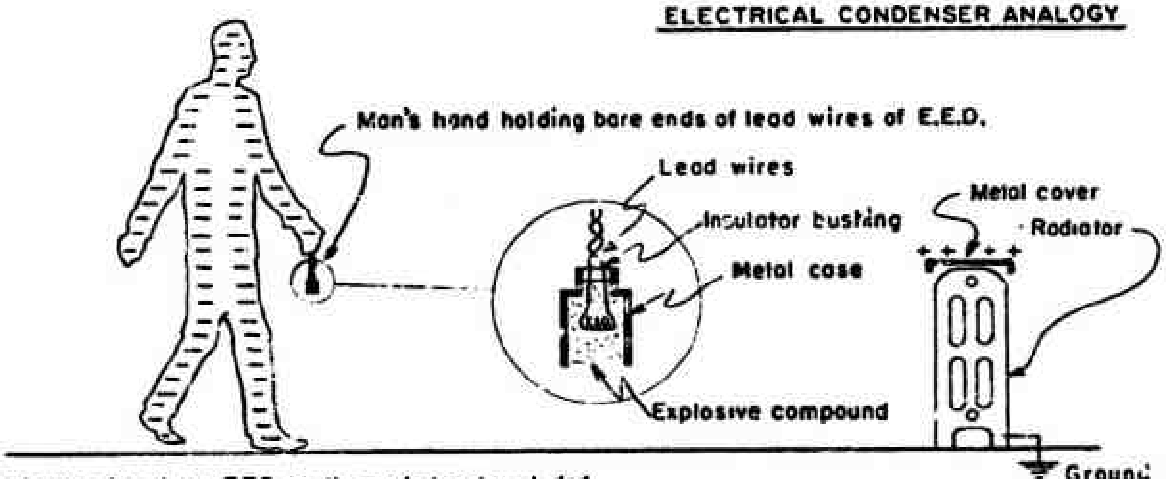
PERSONNEL HANDLING E.E.D.'s

FACTORS CONTRIBUTING TO THE EXPLOSION

1. Man walking across floor generates static charge.
2. Static charge is being accumulated.
3. A path to ground or a body of different potential (the radiator)
4. The explosive or flammable substance, the E.E.D.



ELECTRICAL CONDENSER ANALOGY



When man above placed the EED on the radiator it exploded.

"THIS IS AN ACTUAL CASE HISTORY THAT DID HAPPEN"

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DWG. NO. 1-B

ELIMINATING STATIC SPARK HAZARDS

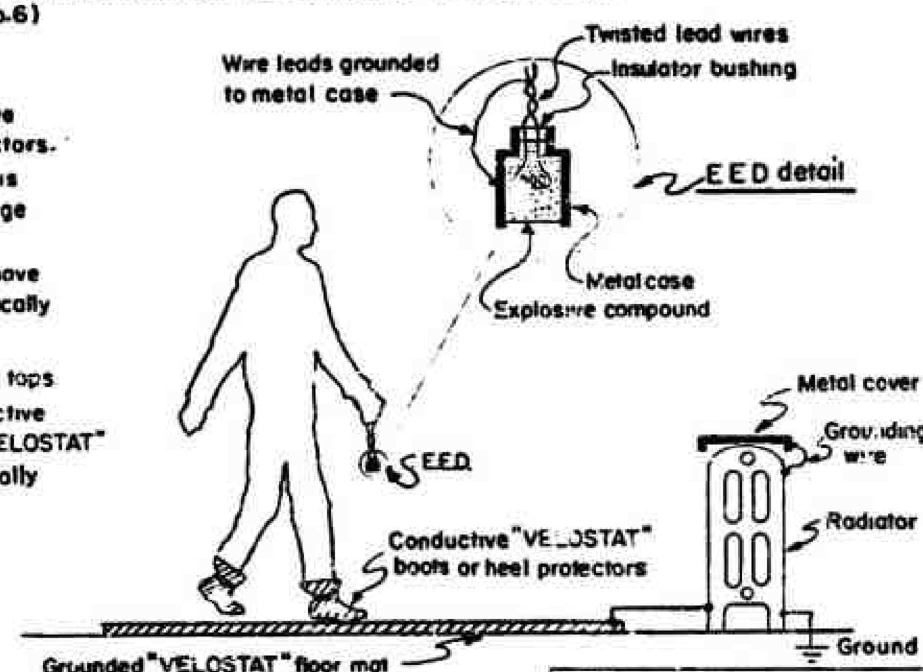
PERSONNEL HANDLING E.E.D's

1. Conductive grounded "VELOSTAT" floor mat in combination with conductive "VELOSTAT" boots drains static charge to ground. (see dwg. No. 6)

A man must wear electrically conductive "VELOSTAT" boots or heel grounding protectors. He must walk on a conductive mat that is grounded in order to drain the static charge to the ground.

When E.E.D's are packaged they must have their lead wires twisted together and electrically grounded to the case. (see E.E.D. detail)

If work benches or stools are used, the tops should have "VELOSTAT" electrically conductive bench tops and the stools should have "VELOSTAT" seat covers, both of which must be electrically grounded. (see dwg. No. 3)



THE SAFE WAY – ACCIDENT WOULD NOT HAVE HAPPENED

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DWG. NO. 2

SERIOUS STATIC SPARK HAZARD EXISTS WHEN ARMING

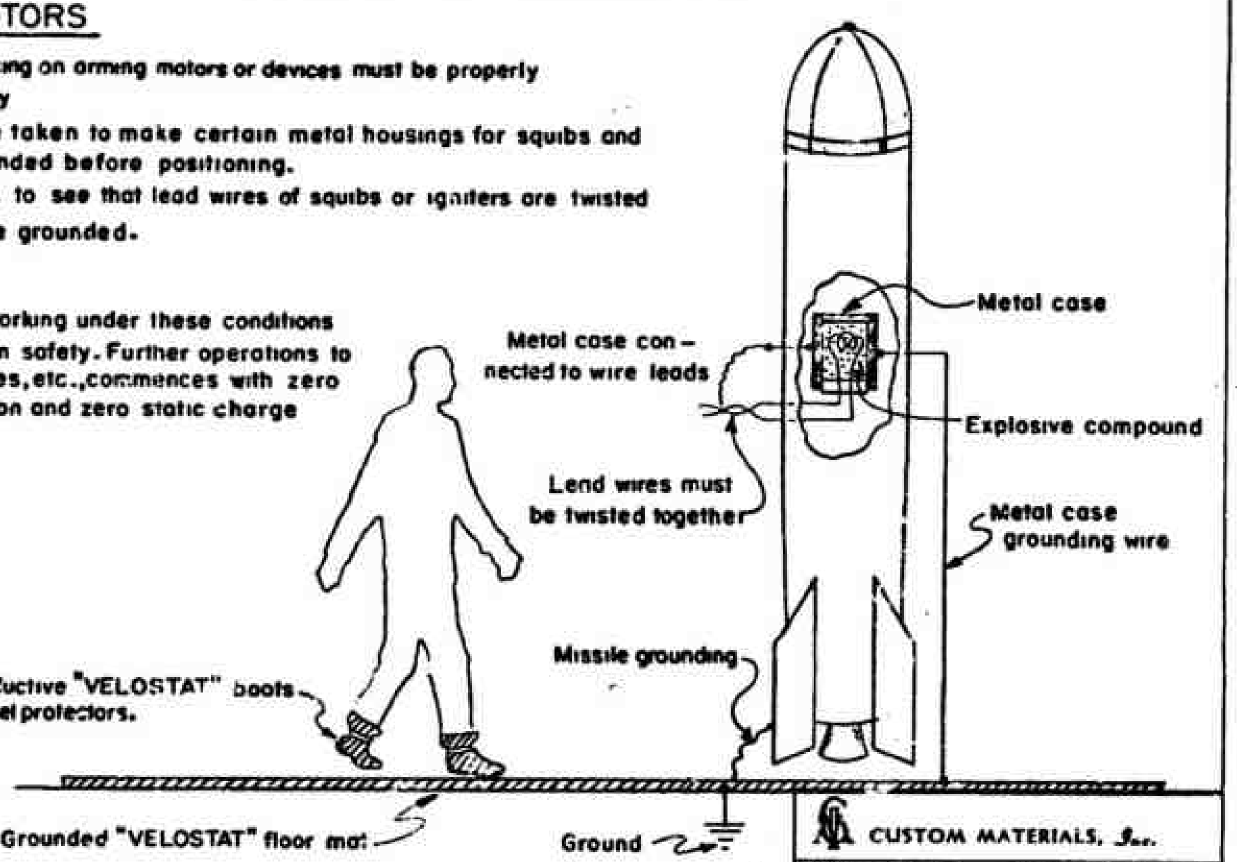
ROCKET MOTORS

1 Personnel working on arming motors or devices must be properly grounded electrically

2. Care must be taken to make certain metal housings for squibs and igniters are grounded before positioning.

3. Always check to see that lead wires of squibs or igniters are twisted together and case grounded.

Working under these conditions provides maximum safety. Further operations to connect lead wires, etc., commences with zero static accumulation and zero static charge potential.



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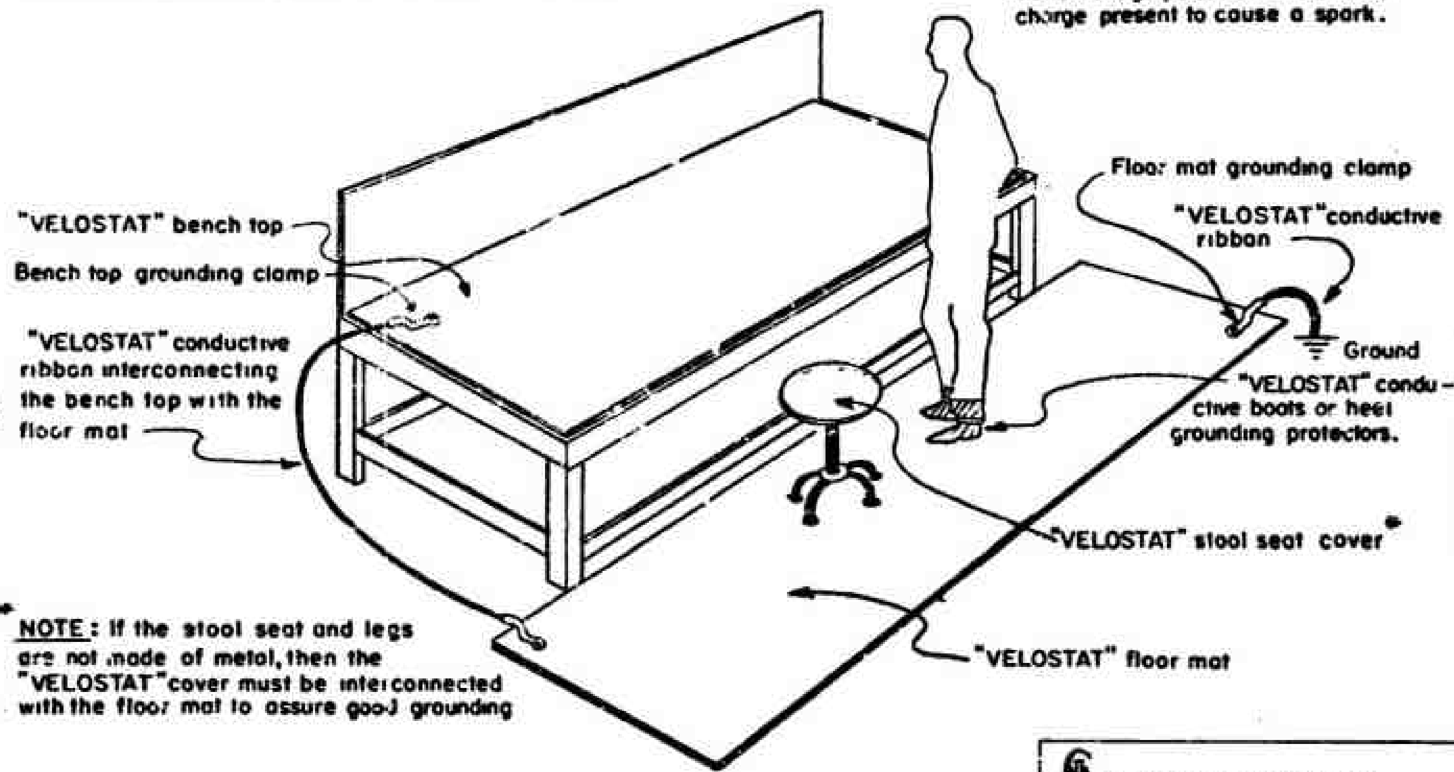
DWG. NO. 3

THE PROPER WAY TO SET UP A WORK BENCH TO ELIMINATE STATIC SPARK HAZARD



*NOTE: If the stool seat and legs are not made of metal, then the "VELOSTAT" cover must be interconnected with the floor mat to assure good grounding

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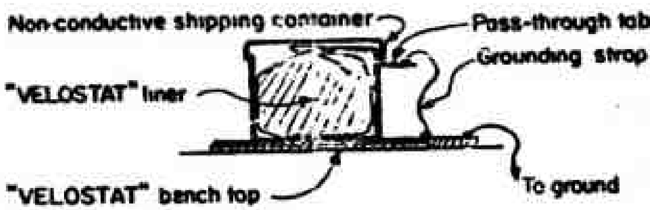
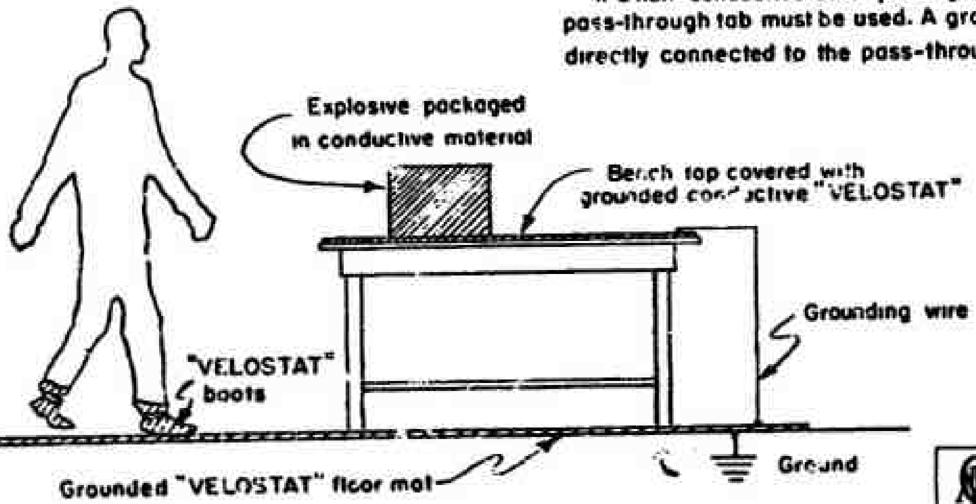
DWG. NO. 4

SAFE PACKAGING OR UNPACKAGING OF E.E.D.'s OR STATIC SPARK SENSITIVE DEVICES



All surfaces, packaging material, as well as the man, are interconnected and grounded. There is no potential difference between any of the items. Everything is in a 100% static-free state.

If a non-conductive outer packaging is used, a conductive pass-through tab must be used. A grounding strap can be directly connected to the pass-through tab.



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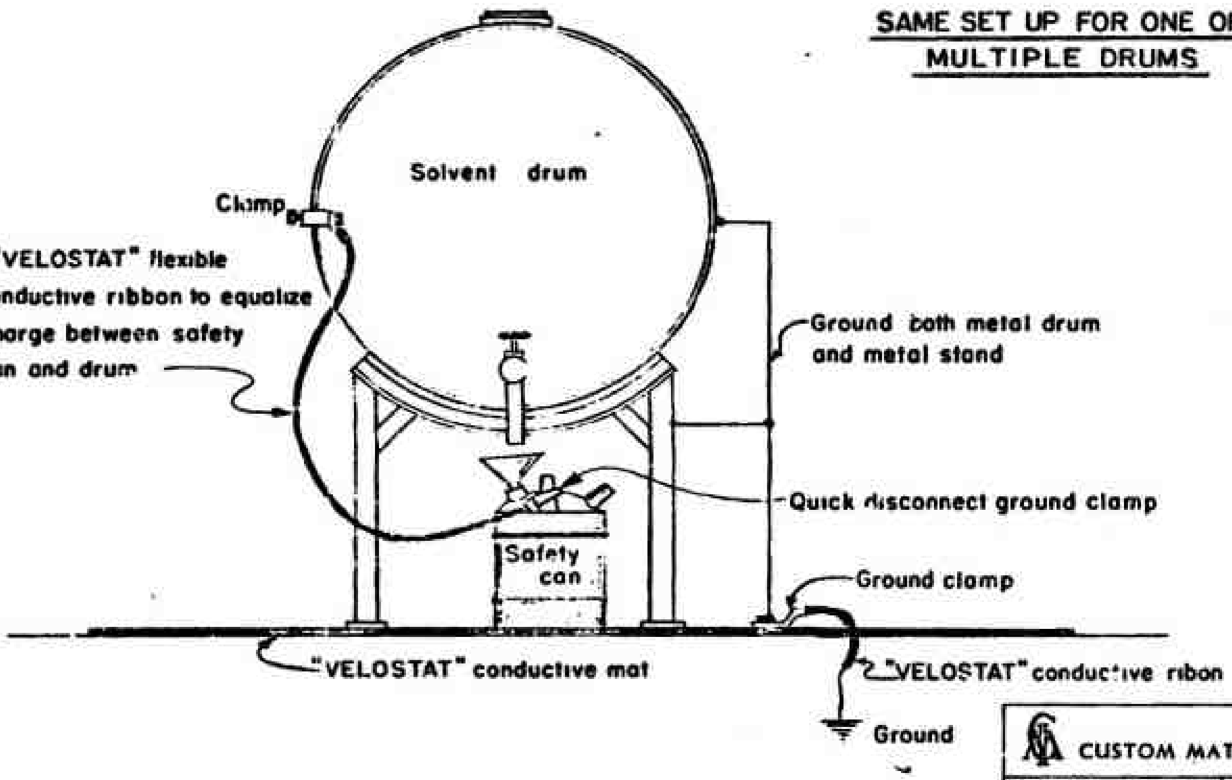
DWG. NO. 5

TYPICAL ARRANGEMENT FOR MAXIMUM SAFETY

HANDLING SOLVENTS AND FLAMMABLE LIQUIDS

SAME SET UP FOR ONE OR MULTIPLE DRUMS



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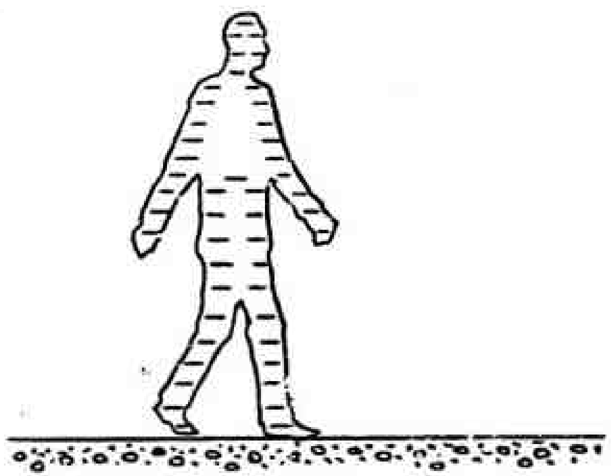
DWG. NO. 6

PERSONNEL GROUNDING

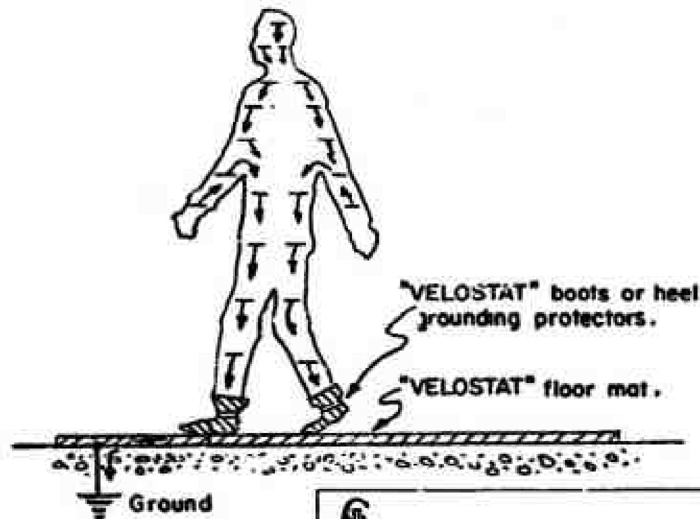
HOW STATIC BUILD UP CAN CAUSE STATIC HAZARD

Static charge build up on this man cannot follow to the ground. There is no conductive path.



THE PROPER SET UP TO ELIMINATE STATIC HAZARD

The "VELOSTAT" boots or heel grounding protectors provide a conductive path for the static charge to be drained instantaneosly to ground. There is no static build up to cause a spark



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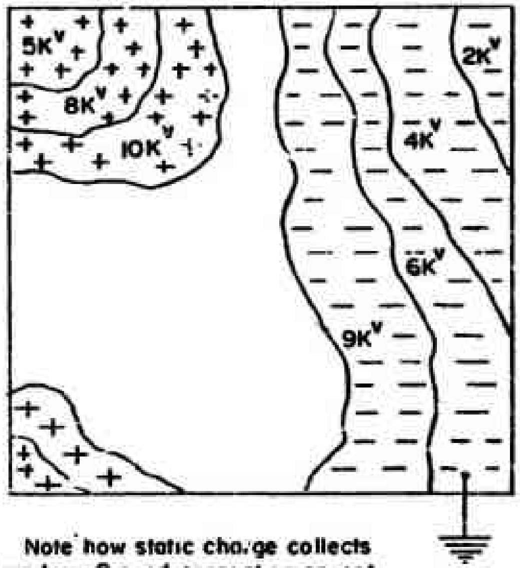
FORM 2500 FRANKLIN PRESS, INC., LOWELL

DWG. NO. 7

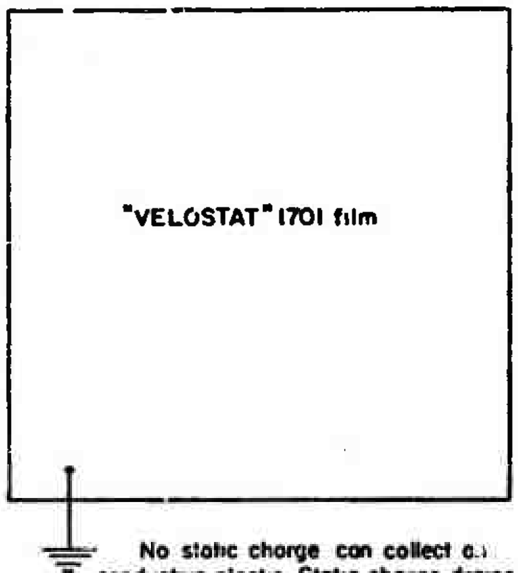
NON CONDUCTIVE PLASTIC FILM



Note how static charge collects at random. Ground connection cannot remove static charge.

GROUND

CONDUCTIVE PLASTIC FILM



No static charge can collect on conductive plastic. Static charge drains to ground immediately on being deposited on the surface of this type film.

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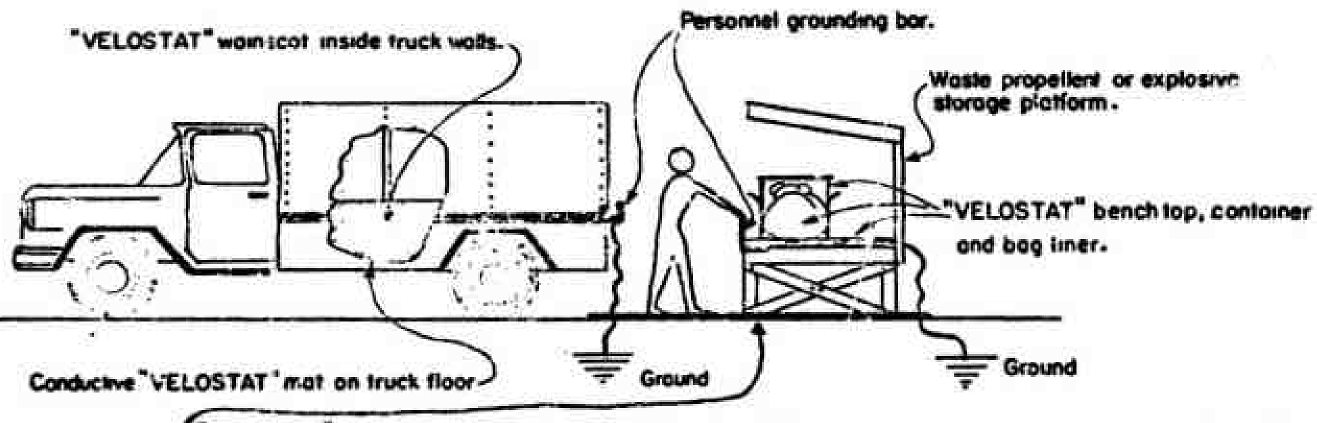
DWG. NO. 8

HANDLING OF W^STE EXPLOSIVES OR PROPELLENTS



"VELOSTAT" ground mat if distance is greater than 4 feet in between truck and storage platform. Personnel must touch grc und ng bar before pic lung up each container, if ground mat is not used.

CUSTOM MATERIALS, Inc.

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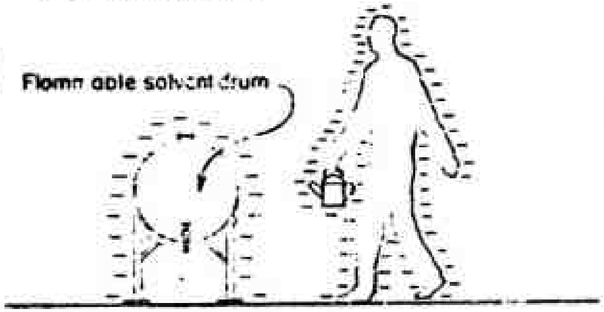
DWG. NO. 9

CONDITIONS UNDER WHICH MANY STATIC SPARK INITIATED FIRES AND EXPLOSIONS HAVE TAKEN PLACE

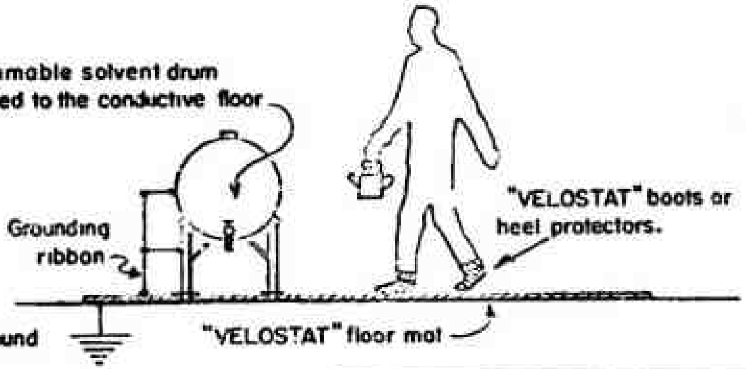
Person approaching the solvent drum to draw off solvent, is highly charged with static electricity due to the motion of walking.

Solvent drum usually possesses a minimum of electrical charge if it stands a long period of time without motion. Static spark can take place anywhere between the person carrying draw off container and the drum hardware.



100% safe conditions against static spark hazard when working with flammable solvents.

Use electrically conductive containers for storing or drawing of solvents. Use conductive plastics or metals. Avoid use of glass containers.



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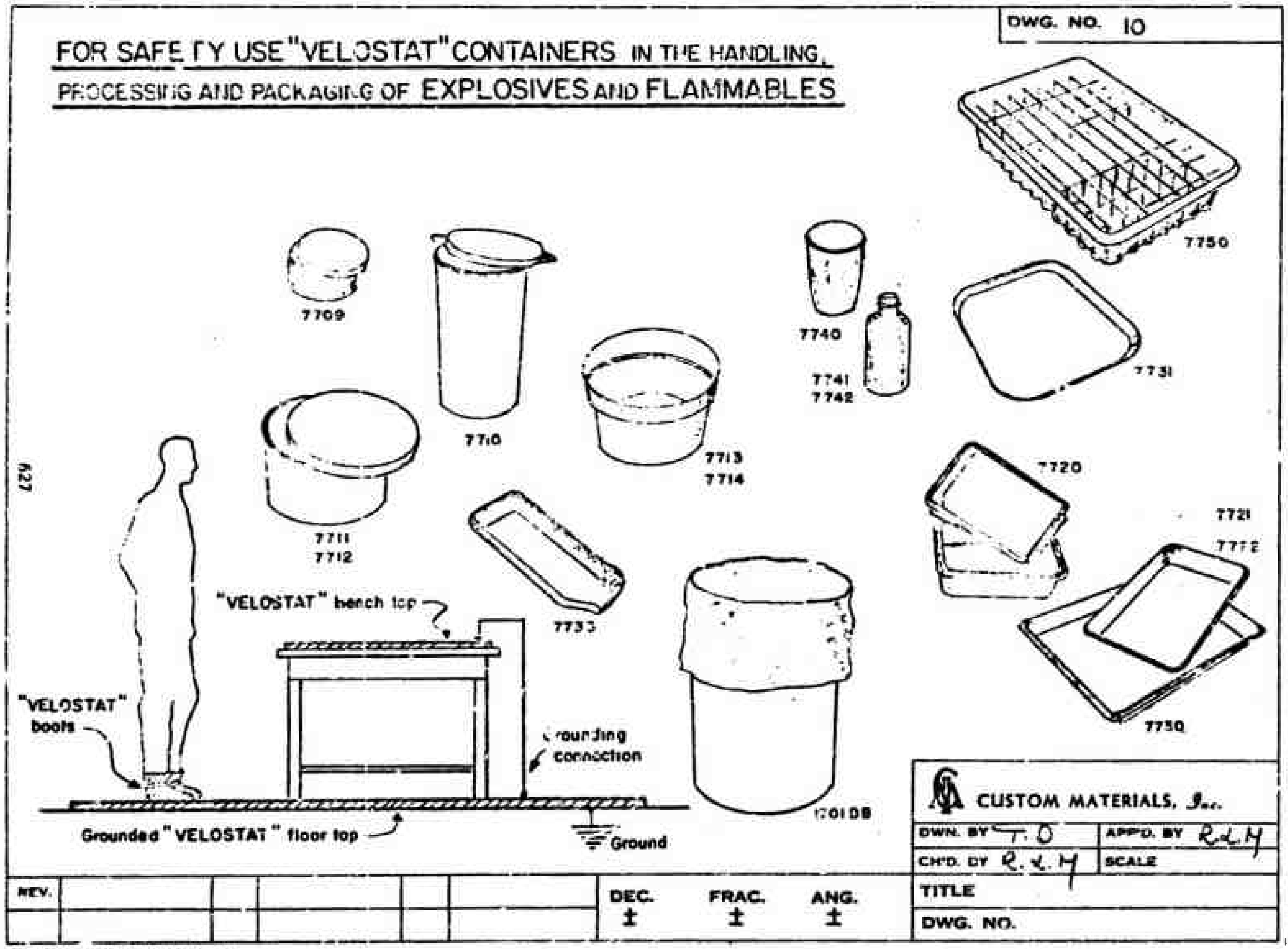

DWG. NO. 10
FOR SAFETY USE "VELOSTAT" CONTAINERS IN THE HANDLING, PROCESSING AND PACKAGING OF EXPLOSIVES AND FLAMMABLES
7709
7710
7711
7712
7713
7714
7740
7741
7742
7750
7731
7720
7721
7722
7730
7733
"VELOSTAT" bench top
"VELOSTAT" boots
Grounding connection
Grounded "VELOSTAT" floor top
Ground
CUSTOM MATERIALS, Inc.
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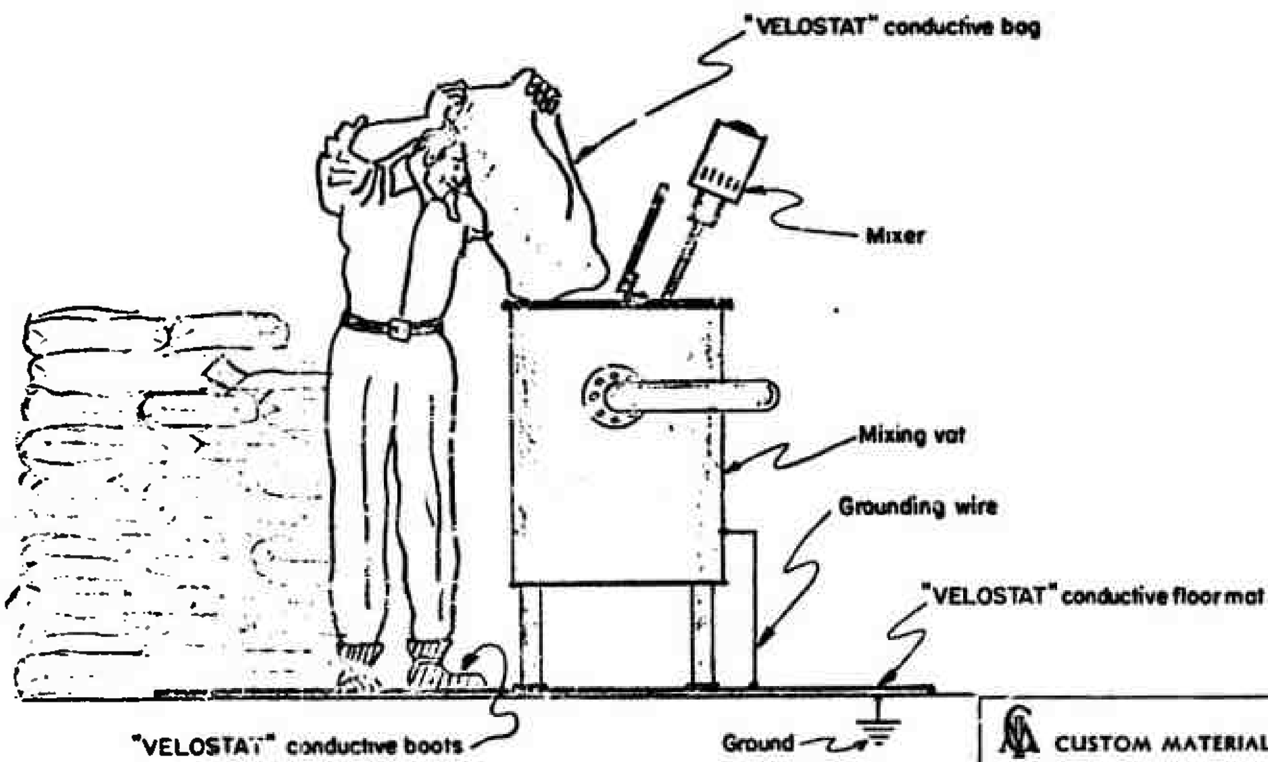
DWG. NO. 11

DANGER OF STATIC SPARK IS ELIMINATED IN HAZARDOUS OPERATIONS, SUCH AS POURING AND MIXING CHEMICAL POWDERS STORED IN ELECTRICALLY CONDUCTIVE "VELOSTAT" BAGS.



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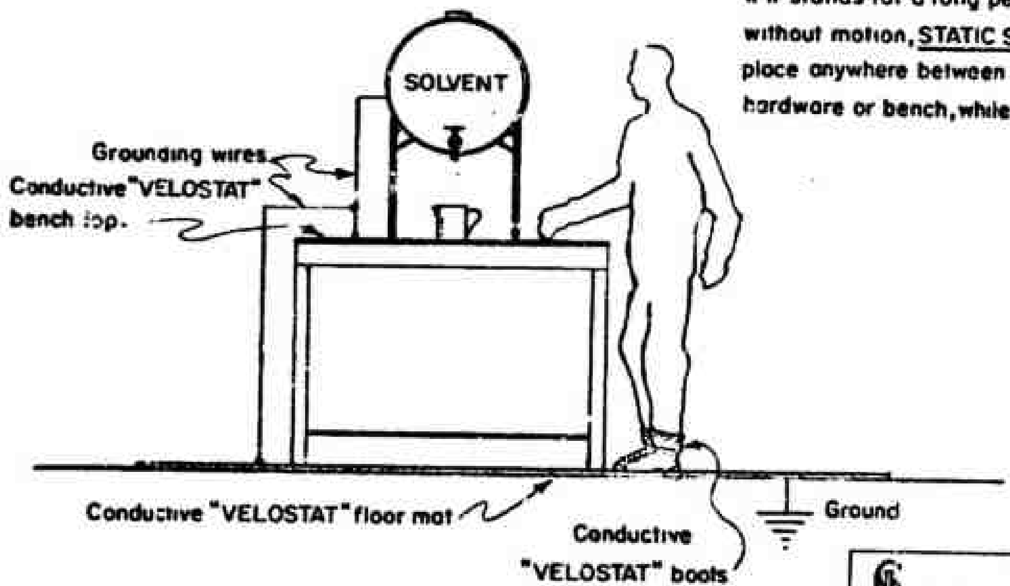
DWG. NO. 12

SAFE CONDITIONS AGAINST STATIC SPARK HAZARD WHEN WORKING WITH FLAMMABLE SOLVENTS

IF NOT PROPERLY GROUNDED, the person aproaching the solvent drum to draw off solvent is highly charged due to motion. The solvent drum usually possesses a minimum of electrical charge if it stands for a long period of time without motion, STATIC SPARK can take place anywhere between the man, drum hardware or bench, while drawing off solvent.



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DWG. NO. 13

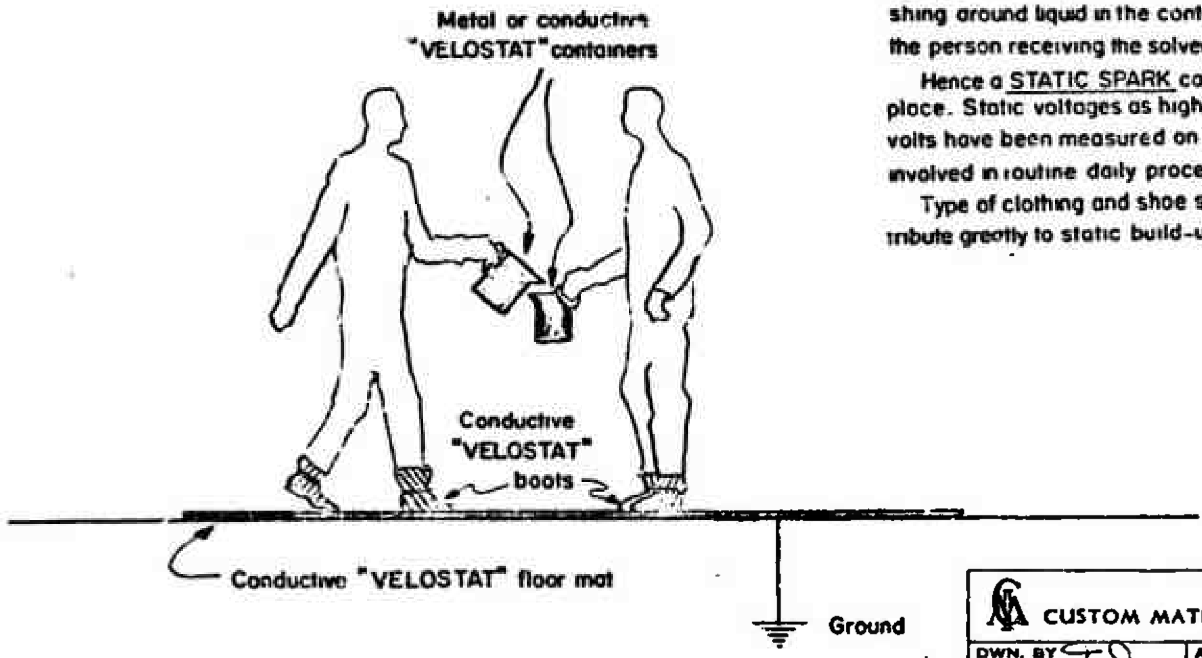
SAFE CONDITIONS AGAINST STATIC SPARK HAZARD WHEN WORKING WITH FLAMMABLE SOLVENTS

Use electrically conductive plastic or metal containers for storing or drawing off solvents. Avoid the use of glass containers.

IF NOT PROPERLY GROUNDED the person pouring the solvent into the small container, has much higher electrical charge caused by motion as well as sloshing around liquid in the container, than the person receiving the solvent.

Hence a STATIC SPARK can take place. Static voltages as high as 50,000 volts have been measured on personnel involved in routine daily procedures.

Type of clothing and shoe soles, contribute greatly to static build-up



CUSTOM MATERIALS, Inc.

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Electrostatic Charge Generation and Auto-Ignition Results of Liquid Rocket Propellant Experiments

by

Dr. E. A. Farber, Principal Investigator
Prof. J.H. Smith, Prof. E.H. Watts, & Mr. J.H. Deese
Florida Engineering and Industrial Experiment Station
University of Florida, Gainesville, Florida

Abstract

This report, one in the series on "Characteristics of Liquid Rocket Propellant Explosion Phenomena", describes experiments carried out with explosive mixtures of liquid rocket propellants and the measurements of the electrostatic charge and voltage generation. This charge and voltage generated increases with the quantities of liquid propellants involved and terminates in actual auto-ignition when large enough quantities are used.

The phenomena and results as reported here were predicted and reported in earlier publications by this group and most recently in "Critical Mass (Hypothesis and Verification) of Liquid Rocket Propellants" by Dr. E. A. Farber, 1971.

Introduction

It has been observed thet when large quantities of liquid fuels end oxidizers are brought togethar, aither during experiments or accidentally, liquid propallant explosions result.

Many different phenomana can trigger chesa explosions (such es flames, sparks produced by striking or breaking metal, hot materials or hot spots produced by slow chemical reactions of fuel and oxidizer, the breaking of crystals which are formed when one of the liquid components fraezes the other and which are broken mechanically or by thermal stresses, or by static electricity which is the result of internal friction and which may produce a spark discharge.

Many mora possibilities could be cited but these additional sources do not chenge the basic picture.

Thus if there is contact or mixing of a liquid fuel with a liquid oxidizer, ignition is possible if en ignition source is available. If not, the mixing process may proceed with more end more of the fual and oxidizer mixing until en ignition source appears either through externel or internal ection.

A previous report of this series "Critical Mass (Hypothesis and Verification) of Liquid Rockat Propellants "[44], goes into decail end presents the theory as well as some experimental results obteined with non-explosive combinetions.

This report presenta verification of the theory and predictions which were made earlier [1,2,4,24,30,42] through the experimentation and meaaurement of the critical parameters involved in the real explosive Liquid Rocket Propellant combinations.

Electrostatic Charge Generation and Auto-Ignition

As mentioned above, many phenomena can provide the source of ignition in mixtures of liquid fuels and oxidizers. In the absence of any external aources of this kind the question arises which if any internal sources can produce ignition.

Among the many internal sources which can produce ignition, one which is always present is the electrostatic charge and voltage generation. It is a phenomenon inherent in the mixing process itself. In other words, it is not possible to mix the propellants under consideration here without at the aame time producing these electrostatic charges and voltages.

To support this it has been well documented over many years that when layers of liquids move across each other that electric double layera are produced resulting in electrostatic charges.[8] If the liquids are good dielectrics so that the charges cannot leak off rapidly, very high voltage differences are generated.

If a medium of lower dielectric constant is interposed between the highly charged liquid layers, electric breakdown can occur and a spark jumps which may well act as the source of ignition, e.g. approximately 2/3 of the voltage gradient in liquid will produce a spark in a gas bubble.

This electrostatic build-up is always present within the mixing regions of fuel and oxidizer of dielectric liquid rocket propellants. Electric discharge is inevitable when the voltage difference has reached the necessary value for breakdown to occur across one of the bubbles produced by the boiling of the constituent with the lower boiling temperature.

This study is rather general but was applied and verified here for mixtures of LO_2/Rp-1 and LO_2/LH_2 propellant combinations of main interest at this time.

It will be shown that the voltage build-up increases with the quantities or masses of propellants involved and the ignition probability reaches a value of one (or becomes a certainty when large enough masses are involved.) When this occurs the quantities which have actually been mixed will be referred to as THE CRITICAL MASS.

Critical Mass

The earlier presentations of this series showed that the charge generation and voltage build-up increase with the mass[24,25,30] or quantities of propellants involved. How rapidly this build-up occurs depends somewhat upon the energy with which the fuels and oxidizers are brought together. Fig. 1 shows this relationship; This is the result of previous work.[44] The significance of this curve is that all values of explodable mixture masses (the quantities involved in producing the explosion regardless of the actual quantities

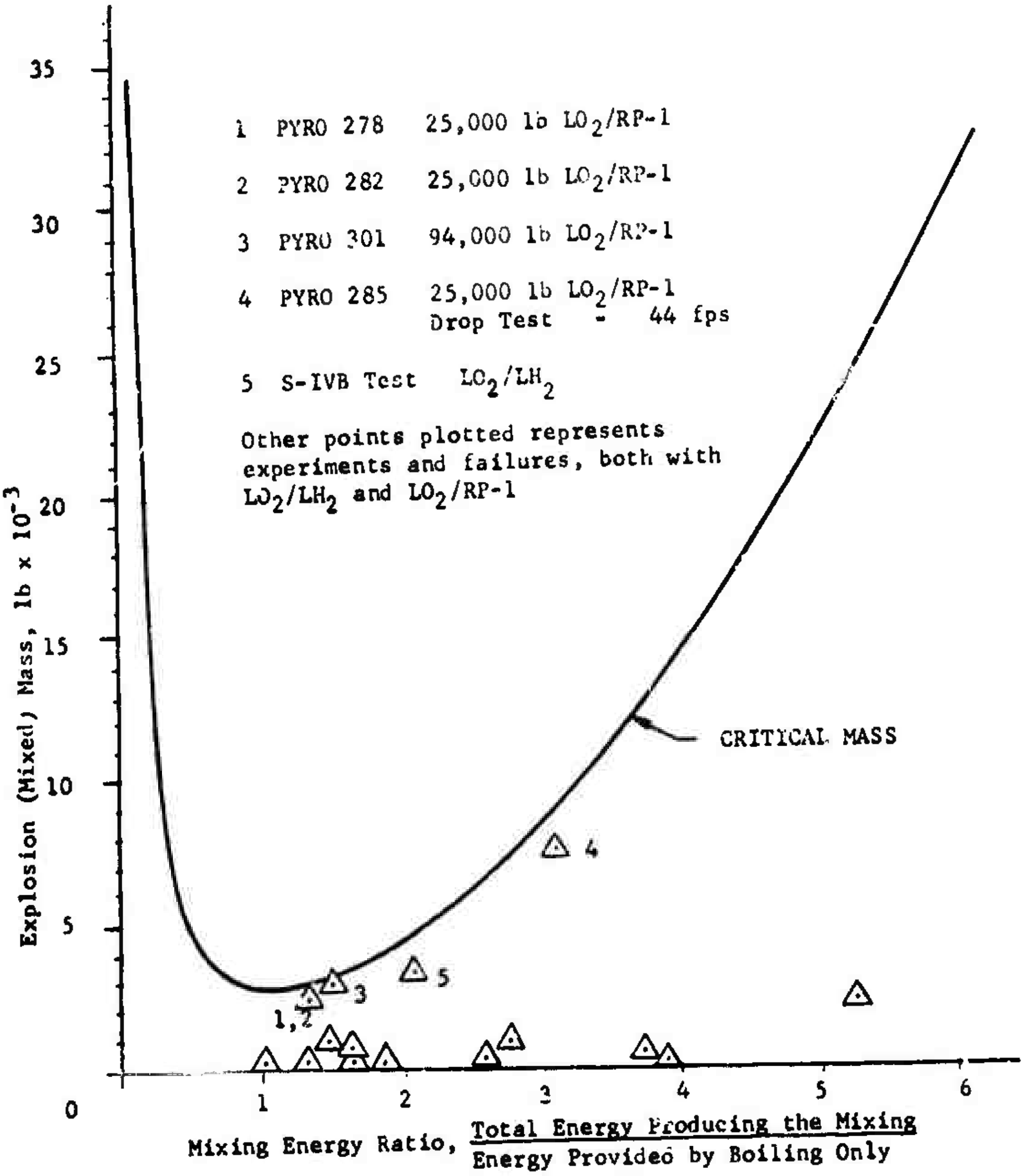


Fig. 1 Explosion Mass - Mixing Energy Relationship

of propallants present) will have to lie below the CRITICAL MASS curve. Thus this curve forms the upper limit or bound for all explosions involving these propellant combinations.

An explosion can and often does occur with quantities smaller than the critical mass but an explosion larger than that predicted by the Critical Mass seems impossible. All presently known experimental and accidental explosions support these predictions.

Experimantal Configuration

To verify tha electrostatic charge generation and voltage build-up, it was necessary to develop an experimental configuration capable of accomplishing this measurement.

Since considerable experienca was gained with methods developed for the liquid propellant mixing studies,[19,28,33,42] and since considerable knowledge was obtained from thesa studies about the behavior of the mixing process, these basic configurations were used in this further work.

Basically this meant that one component was poured into the other undar controlled conditions resulting in the mixing of the components.

a. Inert (Non-explosive) Experiments

The first step in this development was to formulata an experimental procedure which was capable of measuring the electrostatic chargas and voltages generated by the mixing process. To do this safely without the hazard of an explosion LN_2/RP-1

liquids were used. Since boiling characteristics of Liquid Nitrogen ($-320^{\circ}F$)and Liquid Oxygen ($-297^{\circ}F$) are quite similar, this combination simulated LO_2/RP-1 in basic behavior and thus was ideal for laboratory exploratory investigation.

First singe point probes and then two point probes were used to detect the electrostatic charges and voltages generated by the mixing process. These probes were connected to a very sensitive electrometer.

Many mixing experiments were carried out before the first reading was obtained indicating that it was very difficult with a single probe to be at the right place at the right time. More probes were added and readings were obtained more frequently. Finally, screens were used forming multi-point probes and with this arrangement charge and voltage readings were obtained in every single experiment.[28,33]

Further work optimized these configurations resulting in the use of two 1/16 inch mesh screens spaced about one inch apart.

Basically this arrangement was used in all the future series of experiments.

Fig. 2 shows this experimental arrangement with the instrumentation used throughout.

This work with the inert, non-explosive combinations showed that charge generation and voltage build-up are an integral part of the mixing process and cannot be separated from it.

The effect of different combinations upon the charge generation and voltage build-up was studied as well as the effect of quantities

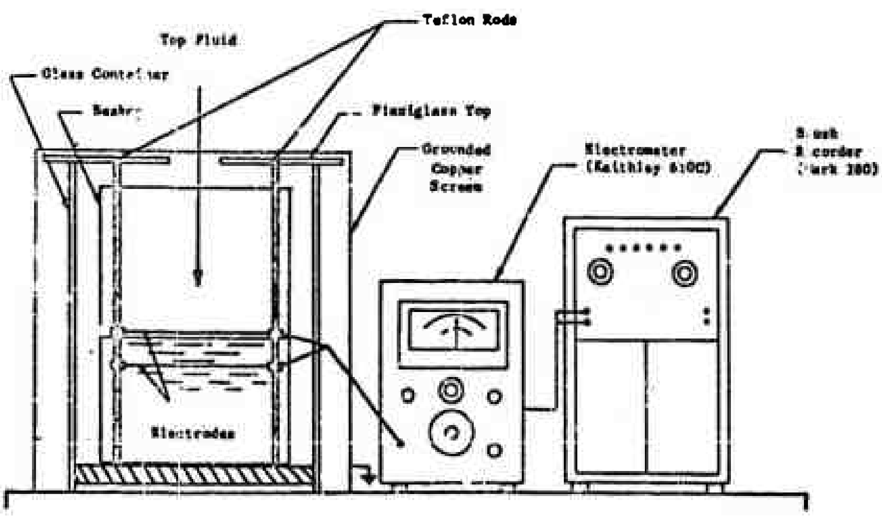


Fig. 2 Laboratory Set up for Mixing Inert Liquids

of propellants present: the larger the quantities of propellants present, the larger the charge generation and voltage build-up. Also the greater the energy available for mixing, the greater the charge generation and voltage build-up. Both of these results were in excellent agreement with the predictions from the Critical Mass Hypothesis.

b. <u>The 6 Pound Explosive Experiments</u>

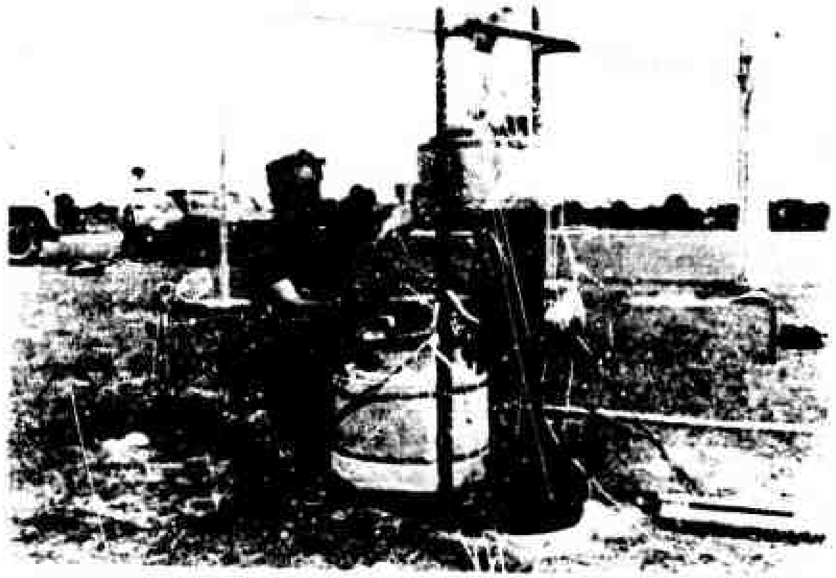
For the actual explosive experiments which were planned and then carried out at the Kennedy Space Center, the experimental procedure had to be modified as well as the equipment. Since the experiments had the potential of an explosion (although none or only a very few were expected with this quantity) precautions requiring remote operation had to be taken.

A test set-up was designed, consisting essentially of two cylindrical containers, a larger one on the bottom and a smaller one on top. The exact dimensions were, Lower Tank: 12 3/4"O.D.X 12 3/4" high, Upper Tank: 8 3/4"O.D.X 8 3/4" high.

The top tank was hinged so it could tip and pour its contents into the lower tank. See <u>Fig. 3</u>. Both tanks had lids and were thermally insulated so as to reduce the evaporation losses of the cryogenic liquids used as fuels and oxidizers.

Temperature probes, consisting of stainless steel sheathed thermocouples, two in each of the tanks, were used; these monitored the liquid levels in the tanks so that proper quantities were in each tank at the time an experiment was started.

The lower tank was fitted with two copper screens, approximately one inch apart, spaced so that they would be surrounded by the



(b)

Fig. 3a and 3b The Six Pound Experiment

mixing region during the experiment. These screens formed the electrodes to measure the charges and voltages generated due to the mixing processes. The signals from the probes and screens were transmitted through amplifiers to the instrumentation van where they were recorded on strip charts and tape. Fig. 4 shows the screens installed in the lower tank.

The test set-up allowed experimentation with any one of the propellants in either tank.

The experimental procedure, described in greater detail in the appropriate section was to fill each tank to the desired level, then by remote operation;

1. Lift the lid of the lower tank.
2. Pull the safety pin on the upper tank.
3. Dump the upper tank.

Records of the probe temperatures and screen voltages were made during the above procedure.

c. The 60 Pound Explosive Experiments

The test set-up for the sixty pound experiments was essentially the same as for the six pound experiments except that the tanks needed were considerably larger. The dimensions were, Lower Tank: 27 1/4"O.D.X 27 1/4" high, Upper Tank: 18 1/2"O.D.X 18 1/2" high.

Fig. 5 gives the experimental arrangement for this series of experiments with the instrumentation part being the same as for the smaller tests except that the stainless steel probes which had proved to be erratic and slow in response were replaced with exposed small thermocouples and the screens were larger in diameter.

Fig. 4 Screen Installation in Lower Tank

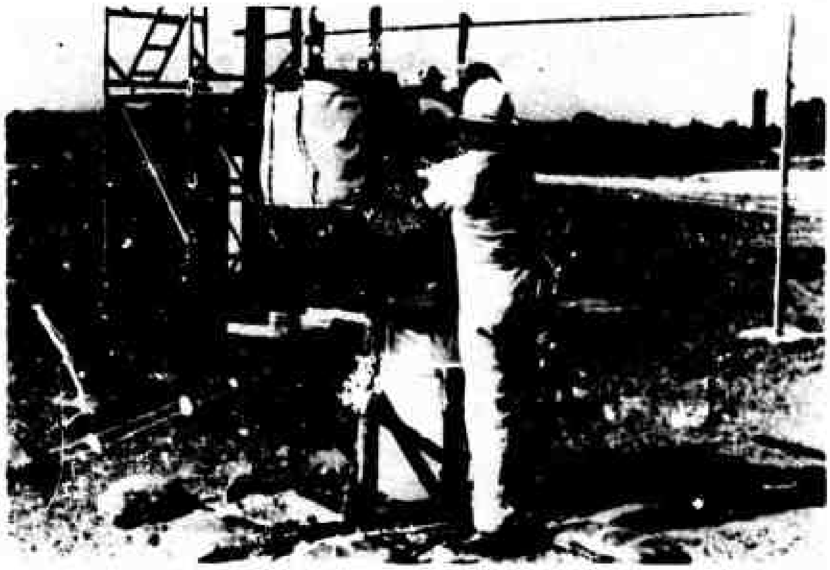


Fig. 5 The 60 Pound Experiment

Fig. 6 The 240 Pound Experiment

The actual operation and running of the experiments was slower since larger quantities of cryogenic fuels and oxidizers were involved requiring longer chill-down and filling times as well as longer warm-up times after the experiments were conducted.

d. <u>The 240 Pound Explosive Experiments</u>

While no actual explosions were expected with the six pound experiments, maybe one or two with the 60 pound experiments (although none occurred for the number of experiments carried out), about one out of ten experiments with the 240 pound quantities was expected to produce an explosion.

The experimental set-up was essentially the same. The tank sizes were, Lower Tank: 43 1/4"O.D.X. 43 1/4" high, Upper Tank: 30 1/4"O.D.X 30 1/4" high. The exposed thermocouple type probes used in the 60 lb. test had not always been able to distinguish between the vapor and the liquid; therefore, these were replaced with heated thermodouples. These would remain cool in the liquid but would heat up rapidly in vapor where the heat gain was considerably larger than heat loss. Also the times for chilling-down, filling, stabilizing, dumping, and then warm-up after each experiment were considerably longer.

e. <u>Fluidic Oscillator Gas Sensors</u>

As an additional experiment not directly connected with the measurement of the electrostatic charge and voltage generation, fluidic oscillators, developed under a separate phase of this contract were used to monitor the H_2 cloud produced by the experiments.

<u>Fig. 7</u> shows one of the earlier designs of this very simple device which can instantanously detect a change in the density

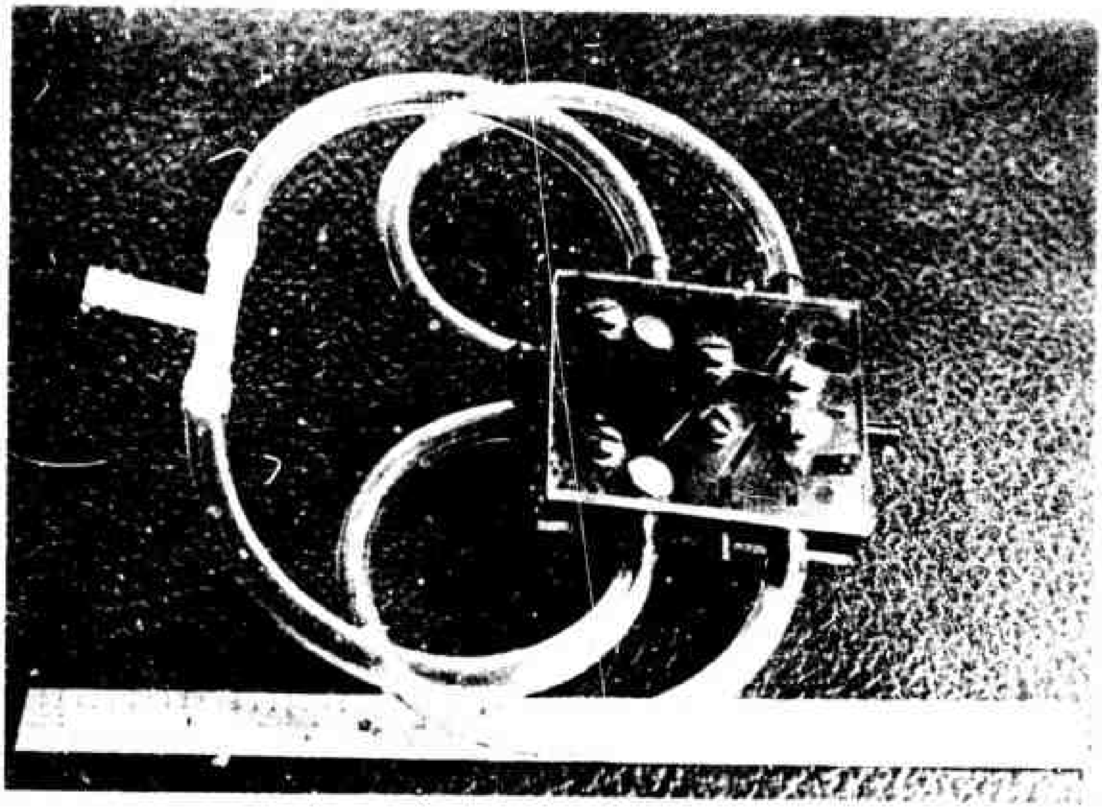


Fig. 7 The [illegible] Oscillator

of a gas going through it, indicating the concentretion of another gas.

The device is simple, easy to make, and inexpensive. A trensistor radio earphone can be used as the trensducer to change the frequency impulses from the oscillator into an electrical signal which can be heard, displayed on en oscilloscope and/or recordod on tape.

The oscillator frequency produced by the gas flowing through the device by applying a vacuum indicates the gas mixture and its concentration. A separate report is being written on this part of the work.

Experimental Procedure

General: The experimentel procedure was designed to allow the filling of the two tenks of the experimentel set-up to the required liquid levels and then allow the dumping of one of the components into the other with the resulting voltege and cherge generation being meesured.

To accomplish this a test procedure had to be written since many people from different support groups were involved et Kennedy Speca Center; this procedure hed to be agreed upon and approved by everyone concerned.

Evaporation or Boil-Off Experiments

The first step in the procedure was to determine the heat losses from the two tanks so that the filling end holding procedure and timing could be worked out

Theoreticel calculetions were made on the evaporetion rates of the cryogenic components and they were experimentelly verified.

The probes, two in each tank were set a certain distance apart and then the tanks were filled to the upper probe and the time determined for the liquid level to drop to the lower probe.

This was done for LN_2, LO_2, and LH_2 for each of the tanks in the 6, 60, and 240 pound experimental configurations.

Actually these boil-off experiments were carried out at the beginning of each of the series involving different quantities.

<u>Charge Generation and Auto-Ignition Experiments</u>

On the morning of each test day the calibration of the instrumentation was verified and the equipment was checked to see that it was recording properly.

The documentary and high speed remote controlled cameras were loaded and readied for the experiments.

With these tasks completed the chill-down of the tanks was started. LN_2 was used first to conserve LO_2 and LH_2. The tanks were both partially filled with LN_2 and this LN_2 then allowed to vaporize; this pre-cooled the equipment for the experiments.

Regardless of whether the LH_2 was to be in the upper or lower tank for the particular experiment the LH_2 flow was started and the liquid level monitored. It took considerable time before the probes showed liquid levels. The lower probe was set at the level required for the experiment and the upper probe at the level to which the tank had to be filled to offset evaporation losses and have the correct quantity of liquid in the tank at the time of dumping.

When the liquid level reached the upper probe the signal was given to terminate flow; then the LH_2 tanker truck was shut off,

disconnected and driven away. This operation took from two to three minutes.

When the LH_2 tanker had cleared the hazard zone the signal was given by the safety director to start the LO_2 flow into the second tank. Again the liquid levels were monitored and this tank was filled to the upper probe and held at this level until the relative timing between the two tank levels was right so that with the proper count-down the liquid levels in both tanks were at the correct level at the moment of dump.

At the command "dump", three control cables were pulled in sequence;

1. to open the lower tank lid.
2. to pull the safety pin of the upper tank.
3. to dump the upper tank.

The high speed camera and the documentary camera were started during the countdown. The recording instrumentation which was running all through the filling operation at low speed was switched to high speed during the countdown to produce maximum resolution for the data taken during the actual experiments. Fig. 8.

After completion of the test it was necessary to wait until the cryogenics vaporized before one could safely approach the test equipment, check it over, and ready it for the next experiment.

This procedure was followed in each case for all the charge and voltage generation auto-ignition experiments.

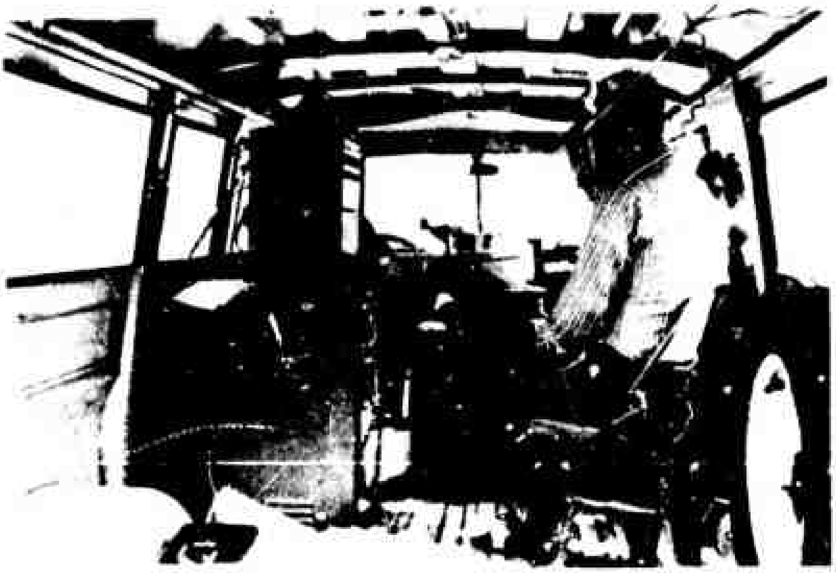


Fig. 8. Instrumentation and Control Equipment

In all cases the LO_2/LH_2 experiments were carried out first since both the LO_2 and the LH_2 vaporized without leaving traces of their presence and no cleaning operation was necessary. When RP-1 was used some of it froze and the waiting period until all the LO_2 vaporized and RP-1 gel melted was considerably longer. It also was necessary to remove any RP-1 which splashed into the upper tank which was to be filled with LO_2 for the next test.

<u>Data and Results</u>

In this section the data and the results of the various experiments will be briefly reported and the significance and deeper meaning of these results will be discussed in the next section.

Evaporation and Boil-off Experiments were necessary to predict the proper timing of the experiments. Evaporation losses occurred in both tanks when filled with cryogenics; safety considerations required these tanks to be filled sequentially. For this reason, theoretical calculations were made as to the rate at which the liquid levels dropped in the tanks and were then verified by experiment.

The results obtained were as follows:

Six Pound Experiments	Calculated Rates Upper Tank	Lower Tank
LN_2	0.131 in/min	0.11 in/min
LO_2	0.08	0.067
LH_2	1.05	1.00
60 Pound Experiments		
LN_2	0.113	0.089
LO_2	0.07	0.055
LH_2	.86	0.72
240 Pound Experiments		
LN_2	0.084	0.08
LO_2	0.053	0.05
LH_2	0.67	0.06

Three different types of probes were used during the experiments. Each successive type was an improvement. Excellent agreement was shown between the experimentation and calculated values reported here.

Charge Generation and Auto-Ignition Experiments

The objective of this series of tests was to determine if electrostatic charges are generated and if so to find their functional relationship to other parameters. An important parameter involved in these experiments is the weight or mass of the propellants involved.

Six Pound Experiments

Figure 9 shows the actual traces from a typical experiment.

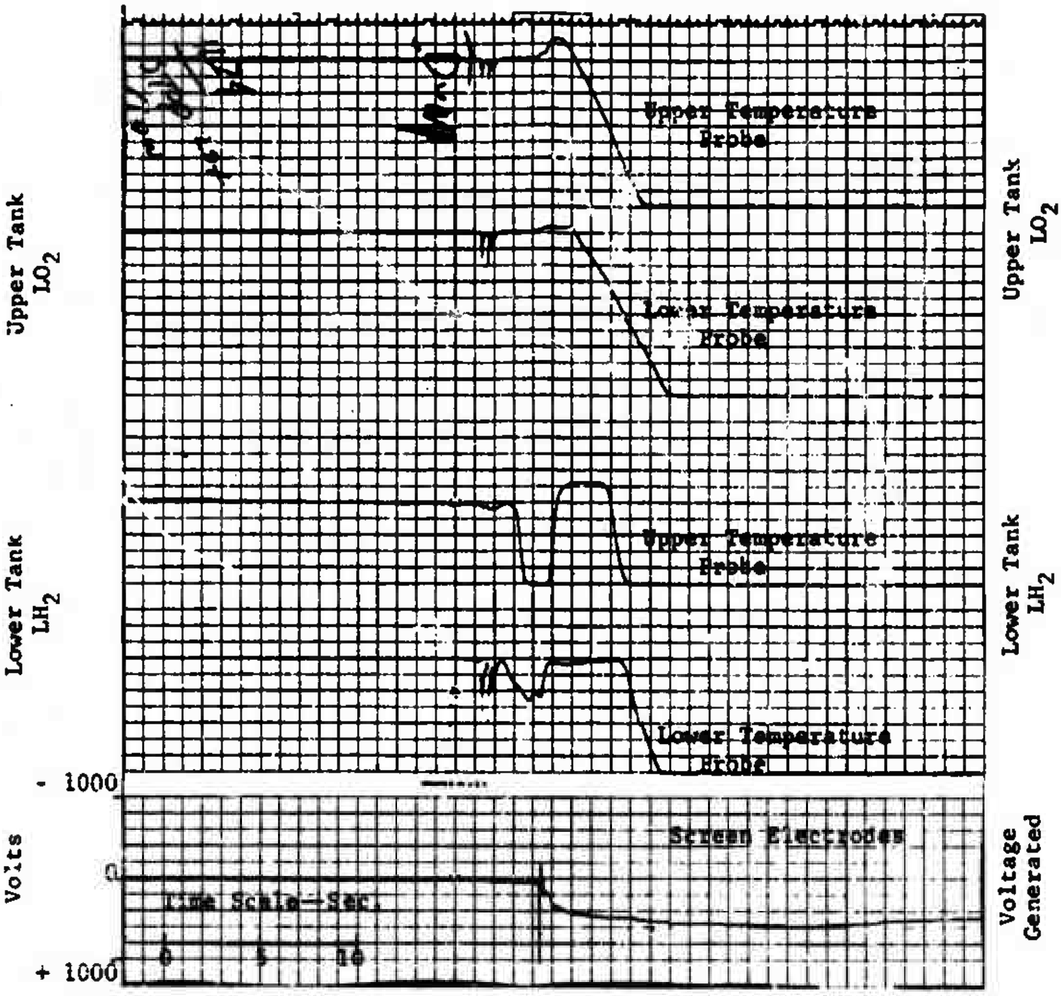


Fig. 9 Chart Traces from the Six Pound Experiment

Recorded on the graph are the upper and lower probe readings in each of the tanks and the generated voltage. Table I lists all the LO_2/LH_2 experiments. It should be noted that the actual voltage generated exceeded the range of the instrumentation in the first five experiments. In the first test the range was $\pm$ 100 volts, for the next four $\pm$ 1000 volts and for the remaining experiments $\pm$ 10,000 volts.

For the LO_2/Rp-1 experiments the range was set at $\pm$ 10,000 volts and after the first eight experiments changed to $\pm$ 1,000 volts to obtain better resolution. Table II presents the LO_2/Rp-1 results.

60 Pound Experiments

Fig. 10 presents the actual traces of a typical experiment, again showing the temperature traces of the liquid level probes in both the upper and the lower tanks and the voltage generation trace indicating the "spike" voltage due to the mixing. Table III presents the results for the LO_2/LH_2 experiments in which the LO_2 was poured into the LH_2. The voltage range was set at $\pm$ 20,000 volts. Table IV presents the results for the LO_2/Rp-1 experiments with the voltage range set at $\pm$ 1000 volts. The voltage range was then changed to $\pm$ 10,000 volts for the LH_2/LO_2 experiments, Table V. In this last set of experiments the LH_2 was poured into the LO_2 in contrast to the first series of experiments with 60 pound of propellants where the LO_2 was poured into the LH_2.

TABLE J

Voltage Data from Six Pound LO_2/LH_2 Experiments
(LO_2 is Poured into LH_2)

No.	Date	Screen Diameter-In.	Voltage - Volts
1	1/12/72	11	+ 40
2			$>$+100
3	1/13/72		$>$+1000
4			$>$+1000
5			+ 350
6			$>$+1000
7	1/14/72		+4800
8			+2800
9			+1600
10			+6400
11			+2000

TABLE II

Voltage Data from 6 lb. LO_2 -- RP-1 Experiments

(LO_2 is poured into RP-1)

No.	Date	Screen Diameter-In.	Voltage - Volts
1	1/14/72	11	+400
2			+ 80
3			+800
4	1/17/72		+ 80
5			-350
6			-140
7			-350
8			-300
9	1/18/72		-240
10			-500
11			-720
12			-760
13			-120
14			-400
15			- 40
16			-200
17			-700
18			-680

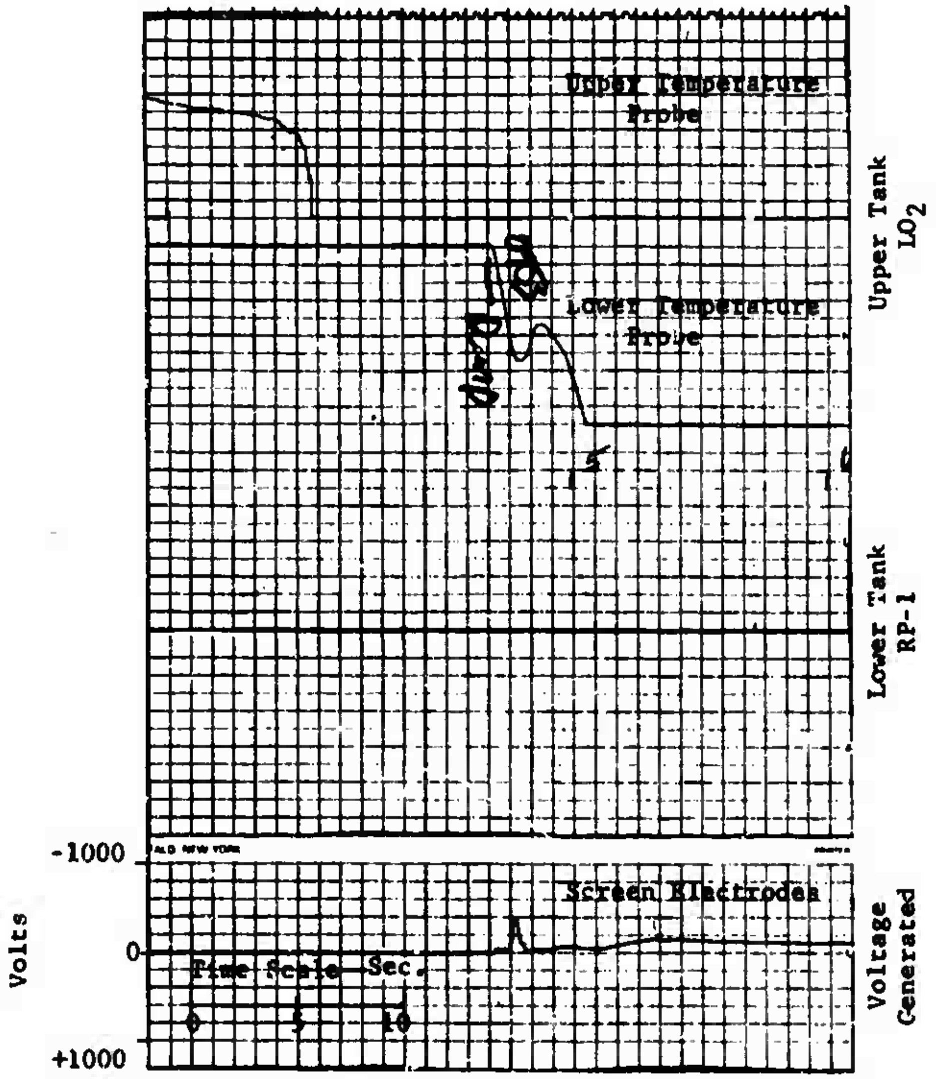


Fig. 10 Chart Traces for the 60 Pound Experiment.

TABLE III

Voltage Data from 60 Lb. LO_2/LH_2 Experiments
(LO_2 is poured into LH_2)

No	Date	Screen Dia. - in.	Voltage--volts
1	1/27	25	+1200
2	1/28		+3200
3			+ 800
4	2/1		+ 800
5			+1600
6			+1600
7			+ 80
8	2/2		+ 400
9			+1600
10			+1100
11			+2800
12	2/3		+1620
13			+ 200
14	2/4		+1300
15			- 500
16			+1000
17			- 600

TABLE IV

Voltage Data from 60 lb. LO_2/RP-1 Experiments
(LO_2 is poured into RP-1)

No.	Date	Screen Dia.--in.	Voltage--volts
1	2/11/72	25	-80
2			-400
3			-200
4			- 80
5			-160
6			-390
7			-380
8			-255

TABLE V

Voltage data from 60 lb. LH_2/LO_2 Experiments
(LH_2 is poured into LO_2)

No.	Date	Screen Dia.--in.	Voltage--volts
1	2/15/72	25	-1000
2			-1000
3			-1000
4			- 500
5			- 500

The 240 Pound Experiments

In these experiments, the ones with the largest quantities of propellants used, the LH_2 was poured into the LO_2 in all but the last two tests. While in those two the LO_2 was poured into the LH_2.

Fig. 11 presents the traces of a typical experiment and Figure 12 the traces of the last experiment in this series, carried out the morning of March 2, 1972, which resulted in auto-ignition and the predicted explosion.

Table VI and Table VII give all the data for the 240 pound experiments with the voltage range set at $\pm$ 10,000 volts for the first day and at $\pm$ 5,000 volts for the remainder of the experiments. Since this series terminated with the explosion, no further runs could be made at this time and the LO_2/RP-1 experiments were postponed.

Discussion

The purpose of the LO_2/LH_2 and LO_2/RP-1 experiments was to verify the Critical Mass Hypothesis which is based upon an ignition source inherent in the mixing process or in other words one which will always be present whenever liquid propellants are mixed.

Among the many possible ignition sources, electrostatic charge generation with attendant measurable voltages is always present. This was shown in the laboratory with inert components such as LN_2 and RP-1 and others. The question, however, remained whether this would be true with the actual propellants used in these tests. All theory indicated that there should be the same

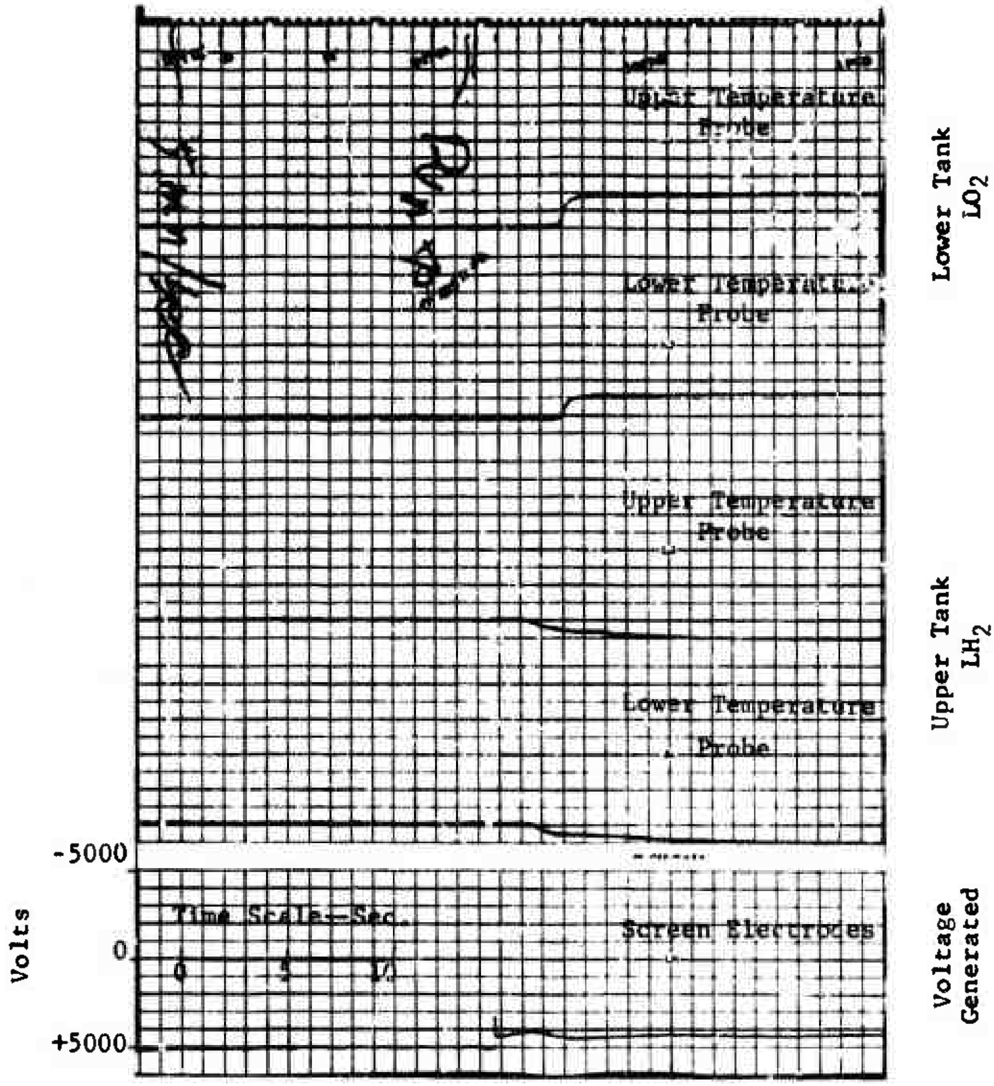


Fig. 11 Typical Chart Traces for a ?40 Pound Test

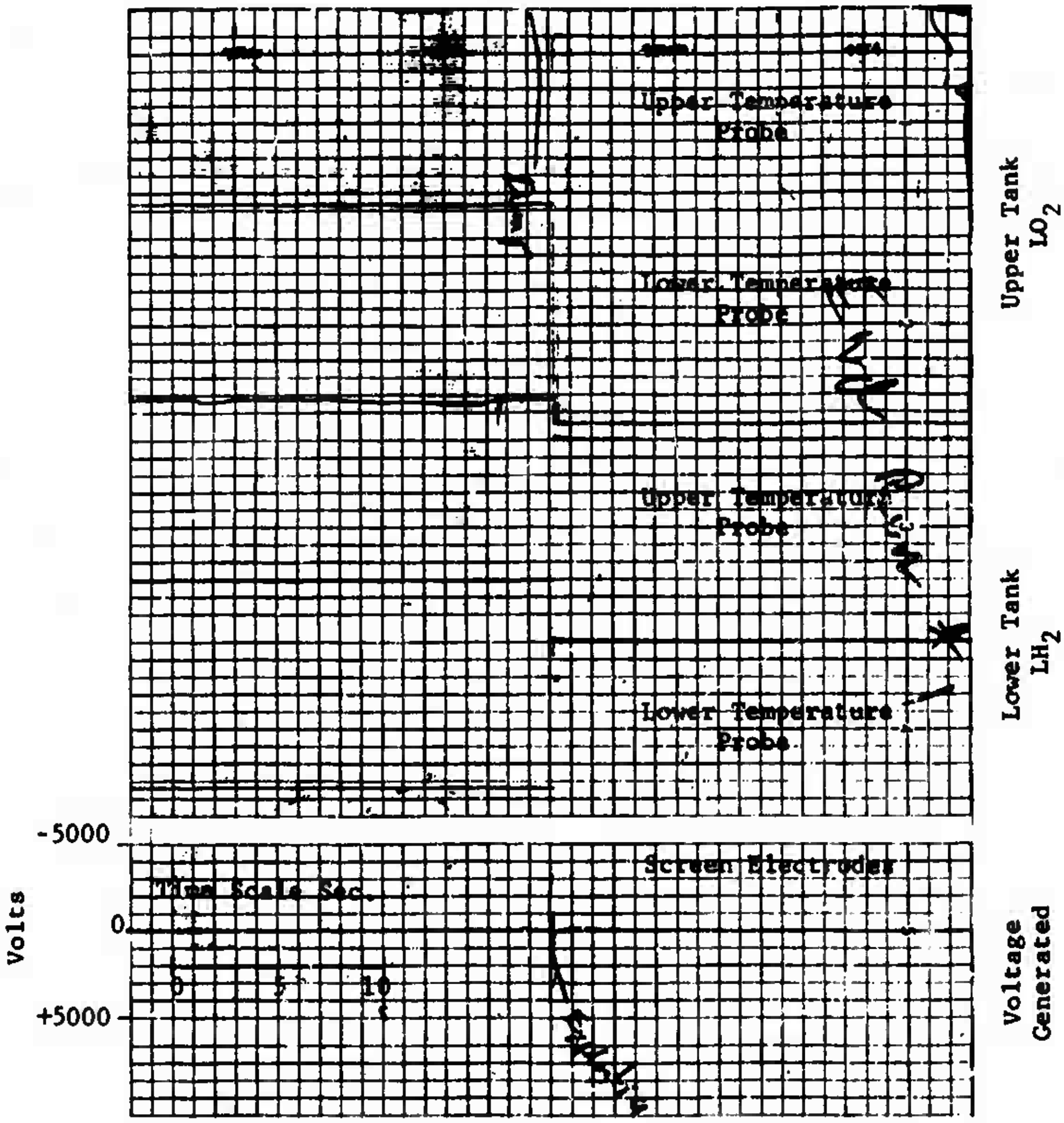


Fig. 12 Chart Traces for the 240 Pound Test Explosion

TABLE VI

Voltage Data from 240 lb. LH_2/LO_2 Experiment
(LH_2 is poured into LO_2)

No.	Date	Screen Dia. - in.	Voltage--volts
1	2/25/72	40	+ 400
2	2/28/72		+ 250
3			+ 600
4			- 200
5	2/29		- 300
6			- 300
7	3/1		$>$ -1700
8			$>$ -1300

TABLE VII

Voltage Data from 240 lb. LO_2/LH_2 Experiment
(LO_2 is poured into LH_2)

No.	Date	Screen Dia. - in.	Voltage--volts
1	3/1	40	+1000
2	3/2		-3300

basic behavior. The voltage and charge generated were predicted from the physical constants of the constituents and the formulation of a physical model, the "Fluid Plug Model", which lends itself to mathematical treatment.[4,30,44]

Basically this is the concept that one fluid falls into the other like a plug and the heat transfer between them will vaporize the other proportional to the contact surface area. The vapor formed makes the fluid plug bob or oscillate giving it a motion similar to that observed in the laboratory with inert systems.

Then electrical analogy was used to transform the mechanical system into an electrical system. This allowed the determination of electrical properties such as voltages, charges, etc. The mathematical treatment involves basic heat transfer equations and vibration relationships coupled with the mechanical to electrical analogy.[4,30,44]

The motion of one fluid layer across the other produced electric double layers of rather high voltages and since the constituents were good dielectrics these voltages built up until discharge occurred across one of the many bubbles formed in the mixing and boiling.

High speed photography of glass contained inert systems showed the size of the great majority of bubbles to be about 1/4 inch in diameter; from this the necessary charge to produce discharge and consequent ignition was determined.

The theoretical work and the inert laboratory experiments were in excellent agreement and were reported in part in the

"Prediction of Explosive Yield and Other Characteristics of Liquid Rocket Propellants"[4] by Farber, et. al. and in more detail in "Critical Mass (Hypothesis and Verification) of Liquid Rocket Propellants"[44] by E. A. Farber.

The tests described in this report were planned, coordinated, and executed at the Kennedy Space Center to determine how closely the previous theoretical and laboratory work predicted the actual behavior of the real potentially explosive rocket propellants.

The most important relationship predicted both by theory and laboratory experiment was that there exists a limit to the amounts of liquid propellants which might be mixed without an explosion. Thus there is an upper limit to the size of explosion which can be produced regardless of the actual quantities of propellants present. The propellants not taking part in the explosion may contribute to the subsequent fire.

To show this relationship between charge generation and mass, tests were planned with quantities of 6, 60, and 240 pounds of propellants and if necessary with 5,000 and 25,000 pounds.

<u>The Six Pound Experiments</u>

These tests were the first ones in the series. Because of the small size they were easiest to handle, and the explosion probability was less. None or possibly only one explosion was expected for the number of experiments planned.

The voltage instrumentation range was set at $\pm$ 100 volts since enough sensitivity was desired to measure any voltage and charge generated even though it was expected that if all parameters

were properly controlled the genereted charge and voltage would by far exceed this value.

Tha first two experiments showed that in both cases the pen of the brush recorder rather violently reached the end of its travel and stayed there.

The range was then changed by one order of magnitude and the following day the next three experiments again each produced enough voltage to "peg the pan", indiceting that more than $\pm$ 1000 volts were ganerated in each case.

The ranga was again increased by one order of magnitude and this time the actual readings wera obtained with the maximum raaching 6400 volts. From the size of tha screens and their spacings the charges which wera generated could ba celculated.

After these experiments with LO_2/LH_2 which produced rather high voltagas in evary tast (thus showing that voltages and charges ara produced in avery case of mixing of these fluids) the experiments were repeated with LO_2/RP-1.

Again voltages and charges ware generated in each case. The actual velues wera smaller than in the LO_2/LH_2 case since the energy available for the mixing process was smaller.

Tables I and II giva tha data for tha six pound series of experiments.

It was falt that tha results from these axpariments varified the predictions and thus no mora tests were required and the program moved on to the 60 pound experiments.

The 60 Pound Exparimants

With the experience gained from the first saries of axpari-ments the 60 pound test equipment was set up and the test procedure repeatad with LO_2 being poured into LH_2. New values wera worked out for evaporation rstes and the corrasponding liquid level drop rates. New filling timas and propar probe settings were determined.

The explosive likelihood in these experiments also was higher with the expectation of possibly one or two of the experiments auto-igniting.

The probes were set at levels which allowed proper timing to carry out tha necessary change-overs in between the filling of LH_2 and LO_2 tanks. The voltage range was left at $\pm$ 20,000 volts to save time and not require recalibration and the change to a smaller range postponed.

A few preliminary experiments were necessary until the timing had been workad out satisfactorily and then the experiments were carriad out just as were the smaller ones with the voltages racorded and tha charges calculated for tha larger screens. Sinca the scraan areas in these exparimants were 5.2 times as large, equal voltage genaration indicatas a charge 5.2 times as large. As shown by equations (1), (2), (3), and (4).

Given $Q = CV,$ (1)

Where,

Q = charge-coulombs

C = capacitance-farads

V = voltage-volts

then for the same voltage generated V, we have by division:

$$\frac{Q_{60}}{Q_6} = \frac{C_{60}V}{C_6V} = \frac{C_{60}}{C_6} \text{ or } Q_{60} = \frac{C_{60}}{C_6} Q_6 \qquad (2)$$

Where,

Q_{60} = Charge developed in 60 pound Experiment.

Q_6 = Charge developed in 6 pound Experiment.

C_{60} = Screen capacitance in 60 pound Experiment.

C_6 = Screen capacitance in 6 pound Experiment.

Also $$C = 0.224 \frac{KA}{d} (n-1) \qquad (3)$$

Where,

A = screen area - in^2

d = screen separation - in (constant)

n = number of screens (constant)

K = dielectric constant (3.3)

C = capacitance - $\mu\mu$ farads

then substitute into (2) and simplify; (due to experimental similarity the K, d, and n values are equal and cancel)

$$\frac{C_{60}}{C_6} = \frac{A_{60}}{A_6} \text{ or } \frac{C_{60}}{C_6} = 5.2 \qquad (4)$$

therefore $Q_{60} = 5.2\ Q_6$ (for the same generated voltage).

A series of these experiments was carried out. Voltage and charges were again generated in each case with the larger screen having more of an averaging effect.

When it was considered that enough of these tests had been conducted the next set of experiments involving LO_2 being dumped into LN 1 were started. The probes were changed to respond to the proper propellant temperatures and the voltage instrumentation range was set at $\pm$ 1,000 volts. The voltages generated and the corresponding charges were again smaller than those produced with LO_2 and LH_2. This was in perfect agreement with the predictions and after it had been established that the voltage and charge generation was present in each of the cases the last set of experiments was initiated.

These experiments involved again LO_2 and LH_2 but this time the LH_2 was poured into the LO_2. The voltage range was set at $\pm$ 10,000 volts. No significant difference was found in the behavior of the first and last series except that the voltages and charges generated with LO_2 dumped into the LH_2 might have generated slightly higher voltages on the average. This can be explained

by the graatar anergy supplied to tha mixing process by dumping the haavier LO_2 into the lighter LH_2.

No explosion occurred in this sarias of experiments, although some of the axperimants, basad upon the theory, came close to auto-ignition.

The actual results are reported for these experiments in Tablas III, IV, and V.

The 240 Pound Experiments

Since the screan area of the 240 pound test is 13.2 times tha six pound scraan area, equal voltage generation indicates a charga 13.2 times as large.

This may be shown as in the 60 Pound Experiment by substituting into equation (1), page 39, and obtaining by division:

$$\frac{Q_{240}}{Q_6} \quad \frac{C_{240}V}{C_6V} \quad \text{or} \quad Q_{240} = \frac{C_{240}}{C_6} Q_6 \qquad (5)$$

Where,

Q_{240} = Charge developed in the 240 Pound Experiment

Q_6 = Charge developed in the 6 Pound Experiment

C_{240} = Screen Capacitance in tha 240 Pound Experiment

C_6 = Screan Capacitance in the 6 Pound Experiment

Combining Equations (3) paga 40, and (5) yialds

$$\frac{C_{240}}{C_6} = \frac{A_{240}}{A_6} = \frac{C_{240}}{C_6} = 13.2 \qquad (6)$$

Therefore $Q_{240} = 13.2\ Q_6$ (for the same generated voltage)

In these experiments it was expected that an explosion would occur; from experimental history it was predicted that one out of ten experiments with LO_2/LH_2 should auto-ignite.

Because of the chill down times and then the filling times it was decided to start with the LH_2 in the upper tank and the LO_2 in the lower tank.

Again the experiments were carried out in the same manner as the earlier ones. The timing improved with the number of experiments carried out and the last three experiments of the first day of this series turned out to be the best ones. It is believed that the first of these came very close to auto-ignition.

The last experiment of that day was carried out by reversing the propellants, having the LO_2 in the top tank and the LH_2 in the lower tank.

The first experiment of the next day, carried out in exactly the same manner as the others, actually produced auto-ignition and the consequent explosion. These data are shown in Tables VI and VII.

The 240 Pound Auto-Ignition

The tenth experiment of the 240 pound series was carried out the same way as all the others. Since it was the first experiment of the day the tanks were first chilled down with LN_2 to conserve LO_2 and LH_2. Then the lower tank was filled

with LH_2 to the desired laval and the LH_2 tanker truck was disconnected and driven away.

The upper tank was filled with LO_2 to the raquirad laval. Then a short waiting period reduced both tank levals to the axact levels desired. At this time the LO_2 from the upper tank was dumped into the lowar one containing the LH_2.

The experiment looked just like all tha others with a vapor cloud appearing from the mixing process. It grew as the others and up to this point the taat proceeded just the same as before.

Then suddenly Dr. Farber observed a small rad glow looking like [illegible]ection appearing near the opening of the lower tank and changing to yellow and then white as it grew. It then rapidly developed into the datonation and explosion with shock wave, fireball, etc. of a typical liquid rocket propellant explosion.

<u>Fig. 13</u> shows six frames taken during this test by the high speed movie camera which was running at 1600 frames/sac. Frames 2 through 6 were taken sequentially prior to and during the explosion. The development of the vapor cloud and the explosion can be seen clearly.

The prediction of an auto-ignition with these quantities of propellants was satisfied and the pradiction that one of ten would produce an explosion (a rough estimate) was exactly met, probably more by coincidence than by design. This again indicates that much can be predicted from theory.

<u>Fig. 14</u> shows a plot of the generated charge ratio (to bring all measurements to the same basis) versus the quantity of

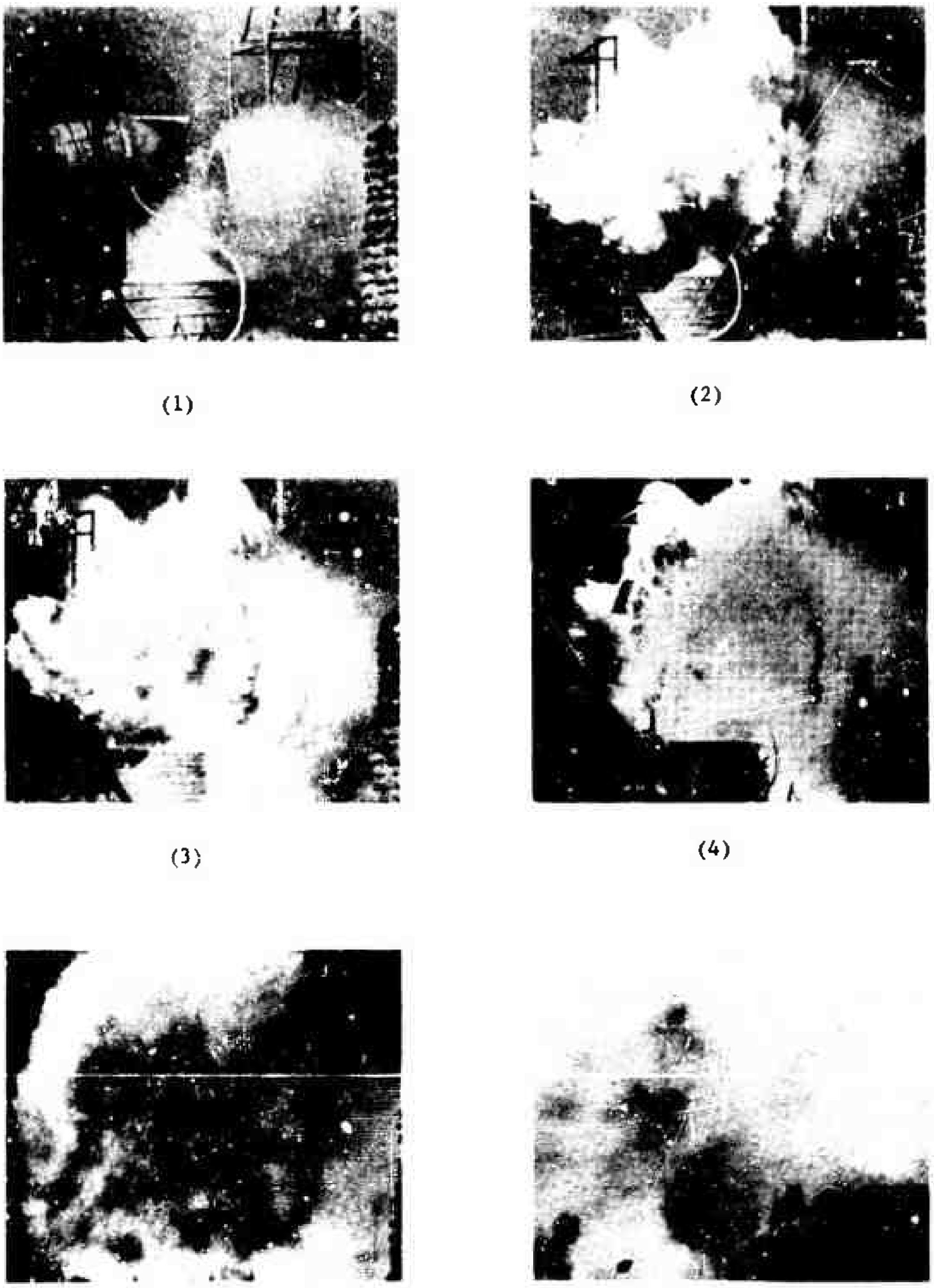


Fig. 13 The 240 Pound Test Explosion Sequence

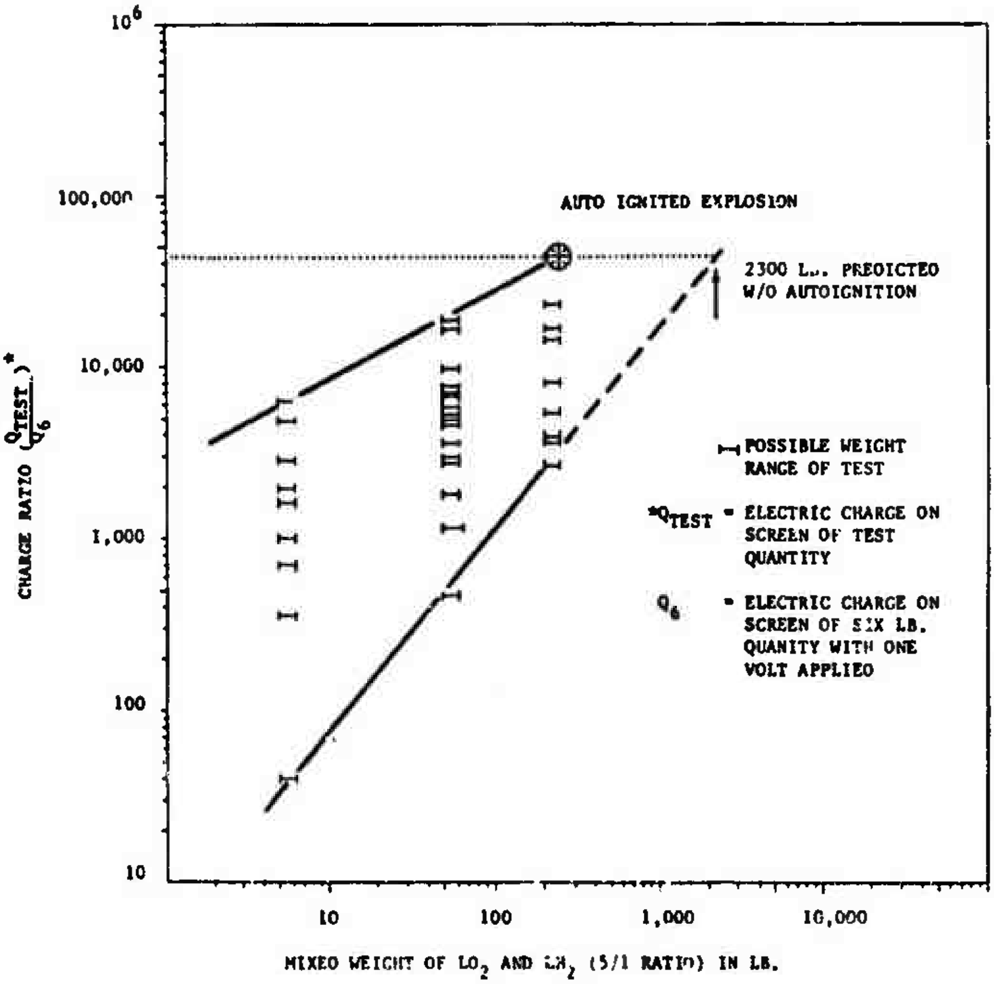


Fig. 14 Charge Ratio as a Function of Propellent Weight (LO_2/LH_2 Mixtures)

propellents involved.

In this plot the lower bound of all the charges generated can be extrapolated to produce auto-ignition with a mass of about 2300 pounds, a value predicted about four years earlier.[4,30] When that value of charge producing auto-ignition is reached by a smaller mass it will explode.

Again it should be emphasized that the theory and its verification by these experiments predicts that auto-ignition becomes a certainty when the masses become large enough reaching the Critical Mass. Below the critical mass quantities the probability of an explosion due to auto-ignition should decrease with decreasing mass, or in other words the smaller the mass the less likely is an auto-ignition. Since the probability of auto-ignition is not zero, however, for masses smaller than the critical mass explosions with these quantities can and do actually occur.

In these experiments there were no auto-ignitions with the six or 60 pound masses but one out of ten with the 240 pound masses.

This explosion verified auto-ignition from self generated charges in the mixing process of the experiment; therefore, this series of experimentation was terminated. A new series is planned, however, which will use considerably more instrumentation and measure such things as ignition point, shock wave propagation velocity and reaction front velocity, and other parameters of importance for the better understanding of liquid rocket propellant explosion phenomena. These additional data (yet to be obtained)

are not necessary to prove the Criticel Mass Hypothesis.

Fluidic Oscillator Gas Sensors

During e number of the experiments the fluidic oscillator gas sensors were used to monitor the H_2 cloud and the signal was recorded on tape. The analysis showed that the sensors quickly measured the H_2 concentrations in air sensing the variations in the cloud concentration as it was driven past the oscillator by the wind. Concentrations of up to 5 percent were recorded. The detailed results will be reported separately.

Conclusions

1. The experiments with the potentially explosive liquid rocket propellants substantiated tha Criticel Mass hypothesis which is based upon the electrostatic charge end voltege generation.

2. Voltages end charges were measured of a magnitude large enough to initiate an explosion if a bubble of the correct size is interposed between the highly charged double layers.

3. The data and results from these experiments indicate clearly that the charges generated are larger when larger quantities of propellants are present, thus increasing the probability for auto-ignition with en increase in mass.

4. The lower bound of LO_2/LH_2 experiments when extended goes to the value of 2300 pounds, the Critical Mass as predicted about four years ago,[4,30] indicating that the probability for auto-ignition reaches the value one at that mass.

5. The last experiment with the 240 pound test shows that auto-ignition is possible with less than the Critical Mass present.

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PROBLEMS IN POLLUTION ABATEMENT WITH

PROPELLANTS, EXPLOSIVES, AND PYROTECHNICS

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The Naval Weapons Center has been tasked by the Naval Ordnance Systems Command (NAVORDSYSCOM), ORD-0332, to determine pollution problems from propellants, explosives, and pyrotechnic (PEP) materials at facilities under the cognizance of NAVORDSYSCOM or the Director of Naval Laboratories.

As part of this determination, the relative magnitudes of the problems were sought through conducting a survey of PEP materials and their ingredients and by-products which may become effluents into streams, PEP burned or detonated as scrap, and PEP burned or detonated for test purposes. This study has been conducted for the Government-owned and operated (GOGO), Government-owned, Company-operated (GOCO), and Company-owned Company-operated (COCO) facilities. In addition, general responsibilities for recycling explosives have been designated to NWS/Yorktown, Virginia, for recycling pyrotechnics to NAD Crane, Indiana, and for recycling propellants to NOS/Indian Head, Maryland.

The scope of the survey was meant to cover all materials as indicated in Figures 1, 2, and 3. These were grouped under the broader categories of propellants, explosives, and pyrotechnic (PEP) materials. Questionnaires were sent to participating activities as listed in Figure 4, seeking data as to the amounts and types of PEP materials burned as waste, detonated or burned in testing, and getting into ground water as pollutants. Gas emissions such as CO, NO_x, SO_2 were included in the calendar year 1970 survey. N[illegible] F)/ Fort Lauderdale, Florida; Solomons, Maryland; and Fort Monroe, Virginia results for 1971 were reported under NOL/White Oak. NAD/St. Julien's Creek results for 1971 were reported under NWS/Yorktown. The Naval Amphibious Base/Coronado, California (Naval Gunfire Range) reported the PEP content of ammunition expended during 1971 under testing. This ammunition was expended during Pacific Fleet maneuvers using the Naval Gunfire Range at San Clemente Island, which is a NAVORDSYSCOM facility.

The results of the calendar year 1970 survey are listed in Table 1. The PEP materials are listed separately by system. PEP materials burned or detonated for tests are first listed separately and then totaled with that for scrap. Table 2 lists the results of the survey for calendar 1971. Here, individual materials burned and detonated for tests are listed separately. Table 3 is a comparison of 1970 and 1971 results for major scrap items. The totals for just the items listed are about the same for each year. However, the table shows considerable change in quantities disposed of for the major items. The 1970 complete totals included approximately 5,650 tons identified as PEP materials without hardware of which there were 3,317 tons of propellant, 2,006 tons of explosives, and 329 tons of pyrotechnics. The 1971 totals can be broken down for the sake of comparison as approximately 6,718 tons identified as PEP materials without hardware of which there are 3,245 tons of propellants, 3,276 tons of explosives, and 196 tons of pyrotechnics.

Tables 4 and 5 list for calendar years 1970 and 1971, by gross tonnage, the twenty largest items of ammunition, explosives, and other dangerous articles (AEDA) awaiting demilitarization. Table 6 lists the PEP materials contained by these items. The gross tonnage for 1971 is 83% of that for 1970; while the PEP content of the ordnance is 68% of that recorded for 1970. In 1971, either none or insignificant amounts of Tetryl, Composition A, B, C type explosives, or White Phosphorous were included in the top 20 AEDA items. Table 7 gives comparative rankings for PEP materials burned and available in AEDA items for calendar years 1970 and 1971.

One of the most significant pollutant gases from burning these materials is HCl, whose final state may be a dilute hydrochloric acid. Its ecological effect has not been established; however, whether burned for scrap or in tests, the average aluminized composite releases about 26% by weight of HCl. So for the 1971 total of about 825 tons of composite destroyed in tests as scrap, 214 tons is HCl. In 1970, of the 460 tons of composite scrap burned, 120 tons was HCl. This is not large when compared with 446 tons of HCl produced by one company alone in burning Minuteman propellant for the Air Force; or what would be used in the Space Shuttle program, which would tend to dwarf the Navy's problem with HCl.

Although, in a rocket exhaust, it is the considered judgement of many knowledgeable people that most of the reaction chamber produced CO is converted to CO_2 downstream in the plume, the precise percentage of CO has not to our knowledge been determined either for rocket exhaust or for burning a propellant as scrap.

The surveys of PEP materials burned or detonated in testing at ORD and DNL sponsored facilities, and the listing of the top 20 AEDA items for calendar years 1970 and 1971 have identified some of the problems the Navy is facing in dealing with waste and/or obsolescent PEP materials.

Possible solutions to these problems are:

1. Recycling (reclaiming - reusing)

This was started, first by the Naval Ordnance Systems Command at the Naval Weapons Station/Yorktown, Virginia and the Naval Ammunition Depot/Crane, Indiana. It is believed that given the ground rule of eliminating pollution from PEP materials wherever possible, almost all ordnance can be recycled. Some would require purification first to recover specification grade materials.

Types of recycling include (a) ordnance returned from the fleet, (b) riser scrap and spillage, and (c) specification grade recovery for any use.

Liquid nitrogen for cracking up PEP materials and cases has been suggested as an approach to increase efficiency of recovery. Electrolytic cutting of ordnance items, which has been used at the Naval Weapons Center for cutting up motors, is one approach to non-hazardous recovery of PEP materials.

2. Burn by diluting in fuel used for heat such as for boilers.

It is suggested that this concept be used at military stations first. (This may use all the available supply.) Solutions and suspensions were considered together with problems of each type.

. Develop recovery processes for materials.

Determine how to separate on a large scale the PEP energetic ingredients from plastics. This would include crushing or grinding methods, swelling, solvent extraction, and physical separation plus chemical attack.

4. Dump in Tectonic Sinks.

These are earthquake type cavities under the ocean in many places which Bostrom & Sherif (Ref. 1) suggest could receive tremendous tonnsges of materials without saturation. The utility of Tectonic Sinks for disposal of wsstes has been reported by E. A. Silver (Ref. 2) who indicates that if the material to be disposed of were deposited at a trench wall and subducted, it would take 10,000 years for one kilometer of sea floor to be subducted.

Where it is much less economical to recycle and return to use for certain materials, modified Deep Water Dump procedures where pollution has been eliminated may be highly useful. (Ref. 3)

5. Biodegradability.

The Army (at Holston Defense Corporation) has succeeded in preliminary work in effecting biodegradation of TNT, RDX, and HMX. Ecological Systems, Inc., under contract to the Naval Weapons Center and Dr. G. Soli of NWC are working on RDX biodegradation. The Naval Ordnance Labatory/White Oak is working with the University of Indiana on TNT biodegradation.

6. Use as additives to commercial explosives such as ammonium nitrate/aluminum slurries in water.

Several companies including IRECO Chemical, Hercules, and DuPont have bought reject material from the Government for this and similar purposes.

7. Chemicals for use in key commercial areas of urgent need.

To modify explosives chemically is usually costly. Therefore, it is necessary to look for areas where the product will fill a need.

Electroreduction (or other reduction) of TNT. Aromatic nitro compounds have been reduced to the corresponding amines which could be investigated alone and additionally modified as necessary for the intended application. Low lead gasoline is one area of interst but this is just scratching the surface of possibilities.

8. Photodegradation of materials.

The use of light alone or in synergism with bacterial biodegradation was brought up by Dr. Albert Noyes. The possibility of use of large remote areas where

water was available was considered. Degradation products could possibly be later used (in places) as fertilizer. Toxicity to animal life would of necessity be considered before a large scale study of this process could be made.

9. Determine ways to reduce scrap and excess munitions, so there will be a smaller problem.

For example, Tooele Army DEpot will in the future use large quantities (more than 190 tons) of Navy ordnance available for disposal, for dividing wall type tests. This will be that much less new ordnance required for such tests, and in turn the ammunition for disposal will not have to be burned in potential violation of pollution abatement regulations.

10. Design of new PEP materials and applications of hardware which will readily accomplish pollution abatement or make it unnecessary.

The Naval Weapons Center has undertaken a program to find water soluble binders which can be used in plastic bonded explosive systems.

11. Investigate the possibility of reusing PEP materials from obsolescent ordnance in current loading operations.

At various Naval Ordnance Systems Command and Naval Laboratory facilities, progress along these lines has been made. In the recycling area, a small scale research program is in progress at NWC. Mr. O. Schneider has conducted a series of experiments. Cartridges (50 Cal) are disassembled, and the propellant powder removed. After blending, the powder is reloaded either alone or in bimodal distribution with a commercial propellant into 30 caliber rifle cartridges for reuse.

Firings were made with powder removed from three separate lots of 50 caliber ammunition, one AP lot, and two Ball lots. All lots were headstamped 1945. All firings were in 30-06 caliber rifles: an M54 Winchester heavy barrel target rifle, and a Springfield MO3-A3. The target barrel was 25-½ inches long; the Springfield had the standard 24-inch barrel. It was found that 50 caliber machine gun cartridge propellant from all three lots would be completely consumed in these weapons using the 173-grain Mk 72 bullet, and with charges of 3.55 grams or more. Charges of 3.50 grams and lighter always left some incompletely burned powder granules in the bore and case. The heaviest charges tried were 3.65 grams. Table 8 shows the charges and the results.

A few "duplex" loads, or bimodal particle distributions were tried. that is a mixture of powder from 50 caliber rounds and finer powder. In every case, those which burned "clean" were of a mixture of 50 caliber MG powder and Hercules "unique" --a fast burning double base propellant used generally for large pistol and shotgun shell loadings. However, it is not necessary to duplex 50 caliber MG propellant for clean burning loadings under the conditions of the tests shown in the table.

The Naval Weapons Center is involved in the design of new PEP materials to accomplish pollution abatement. One promising area is work now being performed with the objective of developing and establishing families of both castable and pressable explosive compositions which will be readily removable from warheads. Water soluble binders will be used as the matrix for such explosives as RDX, HMX, ammonium nitrate, sodium and potassium perchlorates, and other oxidizer and fuel type ingredients.

Conventional TNT-based explosives can be readily removed from warhead cases by virtue of ease of melting and pouring. However, many newer plastic-bonded explosives developed for their special physical properties, or for other characteristics are difficult to remove because they have crosslinked thermosetting bindera. It is therefore necessary to develop explosivea with superior properties which can be used beyond the useful temperature ranges of conventional TNT-based explosives; but which also can be removed easily as a slurry in water and then can be reused, by reprecipitating the polymer on the explosive or by a drying procedure.

It is anticipated that once the general concept haa been shown to be feasible, properties required for current and furture explosives will be more specifically addressed.

A number of water soluble resins which could be used to prepare pressed explosives and monomers which cure to water soluble polymers for cast applications have been studied. The monomer, vinyl pyrrolidone, a low viscosity, readily curable liquid monomer, compatible with most explosive fillers, appears especially promising. Final cured consistency, however, is overly brittle. Therefore, attempts are being made to plasticize this material, either by incorporating nonreactive liquids such as polyglycols or by copolymerizing with other monomers, which, by nature of their molecular structure or reactivity characteristics, may confer greater flexibility.

Initial experimentation indicates that many polyol external plasticizers, even at low percentages, tend to interfere with curing. Furthermore, those compositions which do polymerize readily lack homogeneity, with some portions harder and less tacky than othera. This may be an indication of plasticizer migration with localized

concentration due to lack of compatibility with the solid polymer phase. The best external plasticizer thus far appears to be Antara Gafanol E 400 (polyethylene glycol produced by the Antara Chemical Company) at 1-3% concentrations with vinyl pyrrolidone. Such compositions are flexible and completely soluble in cold water.

Preliminary considerations have also been given to fitting obsolescent small and medium sized rocket motors as free fall weapons. Such factors as detonabitity of the solid propellant charges, compatibility with existing bomb racks, and compatibility with the avionics of the delivering aircraft enter into such studies.

There are various pollution abatement efforts being conducted at other Naval laboratories. The Naval Weapons Station (NWS)/Yorktown has been given responsibility for recycling of explosives from projectiles and warheads. NAPEC/Crane has been given the responsibility for collecting information on quantities of all PEP materials on hand and being stored at various Naval depots and facilities. The Naval Ordnance Station (NOS)/Indian Head has a reclamation plant in design for MILCON and is working on recovering ammonium nitrate and nitrite through "denitration" of nitrocellulose. They are also working on the separation of composite propellant ingredients. Together with the Naval Weapons Laboratory (NWL)/Dahlgren, Indian Head is obtaining background information on rivers and bay water purity. Indian Head also has the problem of disposing of small motors such as Sidewinder and medium sized motors such as Tartar and Talos which are sawed into two pieces and burned. Excess large motors such as Polaris are stored at the Naval Ammunition Depot (NAD)/Hawthorne, Nevada. The Naval Ammunition Depot/Crane, Indiana and NAD Hawthorne have so-called "popcorn machines" for demilitarizing ammunition 50 caliber and smaller. The propellant (smokeless powder) is removed first. NAD Crane is concentrating on pyrotechnics and cartridge actuated device problems, including separation of materials and converting to non-pyrotechnic items. They have indicated that the testing of illuminating flares is their largest pollution problem. The Naval Ordnance Laboratory (NOL)/White Oak has been given some responsibilities for studying and monitoring pollution from deep water dumping operations conducted in the past. Deep water dump operations are presently forbidden. The monitoring is to be accomplished cooperatively with the Woods Hole Oceanographic Institution. They are also concerned with scaling down underwater tests of explosives and with the general pollution type effects of large scale explosives testing.

Supervising these activities, the Naval Ordnance Systems Command (ORD-0332) has been given the responsibility for research and development related to pollution abatement from sources involving propellants, explosives, and pyrotechnics

in the Navy. ORD-0332 has set up the aforementioned pollution abatement assignments at the various Navy laboratories and ordnance stationa.

In conclusion, the Navy is interested in taking an immediate approach to identification, quantification, and solution to its problems of pollution.

Reference 1. Bostrom R. C. and Sherif "Disposal of Waste Materials in Tectonic Sinks", Nature 228, 154-6, (1970)

Reference 2. Silver, Eli A. Subduction Zones: Not Relevant to Preaent-Day Problems of Waste Disposal , Nature 239, 330-1, (1972)

Reference 3. Department of the Navy, Environmental Condition Report for Numbered Deep Water Munitions Dump Sites prepared by the Oceanographer of the Navy C. O. Holmquist, Rear Admiral April, 1972

PROPELLANTS

SINGLE BASE	PLASTICIZERS	TEFLON
DOUBLE BASE	NITROCELLULOSE	VITON
COMPOSITE, PLASTISOL	NITROGLYCERINE	IRFNA
SMOKELESS POWDER	AMMONIUM PERCHLORATE	JP–4/JP–5
BALLISTITE	Be	CTF
HI–EX	Al	HYDRAZINES
THERMOSETTING PLASTICS	Mg	OTTO FUEL

Figure 1. Constituents of ordnance can be broken down into the above systems.

Figure 2. Constituents of ordnance can be broken down into the following systems:

EXPLOSIVES

CAST	PLASTISOLS	PBXN–102
PRESSED	THERMOSETTING PLASTICS	PBXN–103
EXTRUDED	LAMINAC POLYESTERS	PBXN–106
PLASTIC BONDED EXPLOSIVES	THERMOPLASTICS	PBXN–3
TNT	(NYLON, VITON, TEFLON)	PBXN–4
COMP B	Al	PBXN–5
H–6	PBXN–101	PBXN–201
TRITONAL		

Figure 3. Constituents of ordnance can be broken down into the following systems:

PYROTECHNICS

PLASTIC BONDED CAST	LAMINAC POLYESTERS AND OTHER POLYMERS	Cu SALTS
PRESSED		ANTHRAQUINONE DYES
B	VITON	HEXACHLOROBENZENE
Mg	TEFLON	HEXACHLOROETHANE
$NaNO_3$	ANTHRACENE	HEAVY METAL SALTS
$KC10_3$	$SrNO_3$	$TiCl_4$
P	Ca SALTS	

Figure 4. The survey for calendar years 1970 and 1971 disposition of PEP waste materials at NAVORDSYSCOM or related activities included the following:

NTS/KEYPORT, WASHINGTON
NAD/HAWTHORNE, NEVADA
NAD/McALESTER, OKLAHOMA
NSRDL/PANAMA CITY, FLORIDA
NOL WHITE OAK/SILVER SPRING, MD.
NOMTF/WHITE SANDS MISSILE RANGE, N.M.
NOS/LOUISVILLE, KENTUCKY
NAD/BANGOR, WASHINGTON
NUSC/NEWPORT, RHODE ISLAND
NWL/DAHLGREN, VIRGINIA
NWS/CONCORD, CALIFORNIA
NAD/CRANE, INDIANA
NAD–EARLE/COLTS NECK, NEW JERSEY
NWS/YORKTOWN/ST. JULIENS CREEK ANNEX, PORTSMOUTH, VIRGINIA
NOL(TF)/FT. LAUDERDALE, FLORIDA
NOL(TF)/FORT MONROE, VIRGINIA

NOS/INDIAN HEAD, MARYLAND
NAS/KEY WEST, FLORIDA
NURDC/SAN DIEGO, CALIFORNIA
NWC/CHINA LAKE, CALIFORNIA
NWS/CHARLESTON, SOUTH CAROLINA
NWS/SEAL BEACH, CALIFORNIA
POLARIS MISSILE FACILITY–ATLANTIC/ CHARLESTON, SOUTH CAROLINA
AFPRO/AEROJET GENERAL CORPORATION/ SACRAMENTO, CALIFORNIA
LOCKHEED PROPULSION CO./REDLANDS, CALIFORNIA
NORTH AMERICAN ROCKWELL/McGREGOR, TEXAS
NAVAL AMPHIBIOUS BASE, CORONADO, CALIFORNIA (NAVAL GUNFIRE RANGE)
NPRO/HERCULES, INC./MAGNA, UTAH
ABL/CUMBERLAND, MARYLAND
NWS/YORKTOWN

Table 1. Total quantity of PEP materials disposed of by Go-Go and Go-Co facilities during CY 1970, tons.

EXPLOSIVES	
H–6/HBX TYPES	379
TNT	294
TRITONAL	275
TETRYL	165
COMPOSITION A, B, AND C	128
COMBINED AND OTHER	637
EXPLOSIVES TOTAL	1,875
PROPELLANTS	
SMOKELESS POWDER	1,397
DOUBLE BASE	617
COMPOSITE	460
OTHER	476
PROPELLANTS TOTAL	2,950
PYROTECHNICS	
FROM SIGNALS, PRIMERS, ETC.	78
MIXED PYRO	247
PYROTECHNICS TOTAL	325
TOTAL BURNED AS SCRAP	5,153
PEP MATERIALS	
BURNED OR DETONATED FOR TESTS	575
TOTAL →	5,728

Table 2. Total quantity of PEP materials disposed of by Go-Go and Go-Co facilities during CY 1971, tons

	BURNED	TEST
EXPLOSIVES		
H–6/HBS TYPES	932.3	4.1
TNT	729.4	143.2
COMPOSITION A, C	515.0	83.3
COMPOSITION B, CYCLOTOL	184.5	0.8
COMBINED AND OTHER	626.7	57.1
EXPLOSIVES TOTAL →	2,987.9	288.5
PROPELLANTS		
SMOKELESS POWDER	622.6	499.0
DOUBLE BASE	1,106.7	192.2
COMPOSITE	282.6	542.2
PROPELLANT TOTAL →	2,011.9	1,233.4
PYROTECHNICS		
MIXED PYRO	164.4	32.1
SUB TOTALS →	5,164.2	1,554.0
GRAND TOTAL →	6,718.2	

Table 3. A comparison of 1970 and 1971 results for major scrap items burned is as follows:

	1970		1971	
	RANK	TONS	RANK	TONS
SMOKELESS POWDER	1	1,185	4	623
H—6/HBX TYPES	2	1,000	2	932
COMPOSITE PROPELLANT	3	825	5	283
DOUBLE BASE PROPELLANT	4	446	1	1,107
TNT	5	310	3	729
TOTALS		3,766		3,674

Table 4. Twenty largest quantities of AEDA available for disposal (CY 1970)

EADA	QUANTITY EACH	HARDWARE TONS	GROSS WEIGHT TONS	PROPELLANT TONS	EXPLOSIVE TONS	PYROTECHNIC TONS
CARTRIDGE, 20–MM SMOKELESS POWDER TARGET PRACTICE (TP)	72,202,800	21,100	24,920	3,820		
CASE, MINE, HBX LOADED	17,000	7,182	10,200		3,018	
ROCKET 2.25" (MOTOR, INERT HEAD) DOUBLE–BASE BALLISTITE PROPELLANT	115,900	5,707	7,000	1,293		
CHARGE PROPELLANT 155–MM SMOKELESS POWDER	219,800		6,000	6,000		
CASE, MINE TNT LOADED	4,800	2,565	5,700		3,135	
CASE, DEPTH CHARGE, TNT LOADED	19,900	2,102	4,200		2,098	
CARTRIDGE, 50 CAL BALL SMOKELESS POWDER	21,093,200	2,860	3,330	470		
FUZE, POINT DETONATING, MK 78 (CONCRETE PIERCING) TETRYL LOADED	86,500	3,184	3,200		16	
CARTRIDGE, 3"/50 PROJECTILE, TNT, CASE, SMOKELESS POWDER	190,200	2,410	3,104	530	164	
CHARGE, PROJECTILE AND PROPELLING 120–MM SMOKELESS POWDER	15,500		1,300	1,300		

NOTE: SMOKELESS POWDER USED AS A SMALL ARMS POWDER IS PURCHASED UNDER THE "RED DOT," "DUPONT," "BULLSEYE," AND "UNIQUE" TRADE NAMES. SMOKELESS POWDER USED AS A PROPELLANT CHARGE FOR 3 TO 6–INCH GUNS IS A UNIFORM ETHER–ALCOHOL COLLOID OF PURIFIED NITROCELLULOSE.

Table 4 (cont.) Twenty largest quantities of AEDA abailable for disposal (CY 1970)

EADA	QUANTITY EACH	HARDWARE TONS	GROSS WEIGHT TONS	PROPELLANT TONS	EXPLOSIVE TONS	PYROTECHNIC TONS
CARTRIDGE, 30 CAL SMOKE-LESS POWDER	2,000,000	858	865	7		
ROCKET MOTOR, 2.75" DOUBLE BASE BALLISTITE PROPELLANT	88,300	278	530	252		
CHARGE PROPELLING, 16"/50 SMOKELESS POWDER	8,360		360	360		
ROCKET, 5.00", MK 6–4 (TNT LOADED HEAD)	13,550	290	339		49	
BOOSTER, M21A4 TETRYL PELLETS	586,464		260		260	
AIRCRAFT DEPTH BOMB AN–MK 54 MOD 5 HBX–1 OR TNT	1,234	61	200		139	
CARTRIDGE, 3"/70 COM-POSITION A–3, PROJECTILE, SMOKELESS POWDER, CASE	8,767	109	160	44	7	
WARHEAD, 4.5, SMK MK 7–0 WHITE PHOSPHOROUS LOADED	8,846	119	132			13
BURSTER BOMB, ANMIO TETRYL PELLETS	70,000	99	105		6	
GRENADE, M3–1, HEAT RIFLE COMP B	80,000	28	46		18	
TOTALS		48,952	71,941	14,066	6,910	13

NOTE: SMOKELESS POWDER USED AS A SMALL ARMS POWDER IS PURCHASED UNDER THE "RED DOT," "DUPONT," "BULLSEYE," AND "UNIQUE" TRADE NAMES. SMOKELESS POWDER USED AS A PROPELLANT CHARGE FOR 3 TO 6–INCH GUNS IS A UNIFORM ETHER–ALCOHOL COLLOID OF PURIFIED NITROCELLULOSE.

Table 5. Twenty largest quantities of AEDA available for disposal (CY 1971)

	AEDA QUANTITY	GROSS WT. TONS	HARDWARE TONS	EXPLOSIVES TONS	PROPELLANTS TONS
CARTRIDGE, 20–MM, HEI	6,416,909	18,274	15,529	770[a]	1,975[c]
CARTRIDGE, M–96 INCENDIARY	26,371,510	7,400	6,158		1,242[c]
CARTRIDGE, 50 CAL.	53,849,347	6,613	5,700		913[c]
CASE M25 HBX	6,037	5,195	1,633	3,562[b]	
CARTRIDGE, 90–MM	251,101	5,008	3,794	1,214[b]	
BOMB, GENERAL	13,434	3,381	2,710	671[a]	
CASE, DEPTH CHARGE MK 9, TNT	16,323	2,415	919	1,496[a]	
CARTRIDGE, 90–MM	117,857	2,388	1,878		510[c]
MINE, UNDERWATER	1,498	1,447	752	695[b]	
CARTRIDGE, M–95, APT	4,509,087	1,285	1,120		165[c]
TOTALS		59,783	44,100	10,441	5,242

[a]TNT – 3,753 TONS TOTAL

[b]HBX – 6,688 TONS TOTAL

[c]SMOKELESS POWDER – 5,242 TONS TOTAL

Table 5 (cont.) Twenty largest quantities of AEDA available for disposal (CY 1971)

	AEDA QUANTITY	GROSS WT. TONS	HARDWARE TONS	EXPLOSIVES TONS	PROPELLANTS TONS
CASE, MK–36 HBX	2,675	1,177	418	759[b]	
CARTRIDGE, 30 CAL. STD.	41,725,823	1,167	1,017		150[c]
CARTRIDGE, 40–MM	273,033	907	800		107[c]
WARHEAD, 5"	31,361	788	668	120[a]	
CHARGE, DEPTH	53,212	784	296	488[a]	
BOMB, DEPTH	3,693	605	147	458[b]	
CARTRIDGE, 20–MM	1,288,615	375	322		53[c]
CHARGE, PROPELLANT	16,716	230	103		127[c]
CASE, MK–25–11, TNT	245	211	66	145[a]	
MINE, UNDERWATER	442	133	70	63[a]	
TOTALS		59,783	44,100	10,441	5,242

[a]TNT – 3,753 TONS TOTAL

[b]HBX – 6,688 TONS TOTAL

[c]SMOKELESS POWDER – 5,242 TONS TOTAL

Table 6. Breakdown into PEP categories of PEP categories of the largest quantities of AEDA available for disposal, tons

	1970	1971
EXPLOSIVES		
TNT	5,446	3,753
H–6/HBX TYPES	3,157	6,668
TETRYL *	282	—
COMPOSITIONS A, B, C *	25	—
	8,910	10,441
PROPELLANTS		
SMOKELESS POWDER	12,521	5,242
DOUBLE BASE	1,545	—
	14,066	5,242
PYROTECHNICS		
WHITE PHOSPHOROUS *	13	—
TOTALS	22,989	15,683

* EITHER NONE OR INSIGNIFICANT AMOUNTS OF THESE MATERIALS ARE INCLUDED IN THE CALENDAR YEAR 1971 SURVEY.

Table 7. Comparative rankings of PEP materials burned and available in AEDA for calendar years 1970 and 1971.

	1970	
	BURNED	AEDA
SMOKELESS POWDER	1	1
H–6/HBX TYPES	2	3
COMPOSITE PROPELLANT	3	6
DOUBLE BASE PROPELLANT	4	4
TNT	5	2
	1971	
	BURNED	AEDA
DOUBLE BASE PROPELLANT	1	—
H–6/HBX TYPES	2	1
TNT	3	3
SMOKELESS POWDER	4	2
COMPOSITE PROPELLANT	5	—

Table 8. Charges and results for firings made with powder removed from 50 caliber cartridges

NO.	POWDER CHARGE			RIFLE	RESULT	REMARKS
	GRAMS	GRAINS	TYPE			
1	3.25	50.1	MG U16396	M54	U	
2	3.30	50.9	↓	↓	U	
3	3.35	51.7	↓	↓	U	
4	3.40	52.7	↓	↓	U	ALL LOADS WITH "U" RESULTS LEFT SOME UNBURNED POWDER IN THE BORE AND CASE.
5	3.[illegible]	53.3	↓	↓	U	
6	3.50	54.0		↓	U	
48	0.40 2.90	6.17 44.75	IMR 4895 MG U16396	↓	U	
48UN	0.40 2.90	6.17 44.75	HERC UNIQUE MG U16396	↓	U	

NOTE: ALL CASES WERE FA 58 MATCH, PREVIOUSLY FIRED, RESIZED IN THE SAME DIE IN ONE SESSION, TRIMMED TO UNIFORM LENGTH AND REPRIMED WITH WINCHESTER NO. 120M PRIMERS LOT 130. CHARGES, INCLUDING THE DUPLEX ONES, WERE WEIGHED TO THE NEAREST GRANULE OF POWDER. IN DUPLEX LOADS, THE FASTER–BURNING POWDER WAS CHARGED INTO THE CASE FIRST, THEN THE MG POWDER. ALL BULLETS WERE M72, 172–GR CALIBER 30 MATCH, SEATED TO STANDARD CARTRIDGE DIMENSIONS FOR M1 CARTRIDGES. NO ATTEMPT WAS MADE TO KEEP THE FAST–BURNING POWDER NEXT TO THE PRIMER IN THE DUPLEX LOADS.

Table 8 (cont.) Charges and results for firings made with powder removed from 50 caliber Cartridges.

NO.	POWDER CHARGE			RIFLE	RESULT	REMARKS
	GRAMS	GRAINS	TYPE			
7	3.55	54.6	MG 18304	03–A3	C	ALL LOADS WITH "C" RESULTS BURNED COMPLETELY, NO RESIDUE VISIBLE IN BORE OR TAMPED OUT OF CASE.
9	3.65	56.4	MG 18304		C	
U1	0.350 3.000	5.4 46.3	HERC UNIQUE MG T18304		C	
U2	0.350 3.050	5.4 47.1	HERC UNIQUE MG T18304		C	
U3	0.350 3.060	5.4 47.8	HERC UNIQUE MG T18304		C	ALL FIRED CASES SHOWED MODERATE PRESSURE SIGNS AFTER THESE TESTS
7U	3.55	54.8	U16396		C	
7T	3.55	54.8	MG T18243		C	
8U	3.60	55.6	MG U16393		C	
8T	3.60	55.6	MG T18243		C	
9U	3.65	56.3	MG U16393		C	
9T	3.65	56.3	MG T18243		C	

NOTE: ALL CASES WERE FA 58 MATCH, PREVIOUSLY FIRED, RESIZED IN THE SAME DIE IN ONE SESSION, TRIMMED TO UNIFORM LENGTH AND REPRIMED WITH WINCHESTER NO. 120M PRIMERS LOT 130. CHARGES, INCLUDING THE DUPLEX ONES, WERE WEIGHED TO THE NEAREST GRANULE OF POWDER. IN DUPLEX LOADS, THE FASTER–BURNING POWDER WAS CHARGED INTO THE CASE FIRST, THEN THE MG POWDER. ALL BULLETS WERE M72, 172–GR CALIBER 30 MATCH, SEATED TO STANDARD CARTRIDGE DIMENSIONS FOR M1 CARTRIDGES. NO ATTEMPT WAS MADE TO KEEP THE FAST–BURNING POWDER NEXT TO THE PRIMER IN THE DUPLEX LOADS.

AMBIENT MEASUREMENT TECHNIQUE FOR NO_2 - NO

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According to the Environmental Protection Agency (EPA) Air Quality Criteria for Nitrogen Oxides (Booklet AP-84), the important oxides in terms of nitrogen are nitrogen dioxide (NO_2) and nitric oxide (NO). These oxides are usually monitored simultaneously using a single instrument which passes both compounds through an oxidizer and reports them as total oxides of nitrogen (NO_x). The oxidizers commonly used are aqueous potassium permanganate or chromium trioxide absorbed on a solid support. Both oxidizers have limitations. The permanganate solution removes some NO_2 from the air sample, thus, reducing the actual amount measured. The chromium trioxide/solid support system absorbs moisture during periods of high relative humidity, thereby, reducing oxidizer efficiency.

Owing to the limitations found when using the NO_x monitors, a twin monitor station system has been developed, with one station monitoring nitrogen dioxide and the other nitric oxide. The NO_x monitor used is the Technicon® Air Monitor II A, which employs the Lyshkow modification of the Saltzman method. The Lyshkow reagent has been further modified by adding 0.2% triethanolamine. Nitric oxide is monitored using a modified Technicon II A. The modification removes NO_2 by drawing an air sample through an absorbent column (20% w/w triethanolamine on 60/80

mesh Chromosorb P®). The unabsorbed nitric oxide is then bubbled through an acidified potassium permanganate solution and oxidized to nitrogen dioxide, which is subsequently measured.

The system is calibrated using liquid and gas standards. Utilization of the continuous automated system for independently monitoring nitrogen dioxide results in improved absorption efficiency and color production, and in case of nitric oxide a recovery efficiency of 75% which is not affected by high relative humidities.

1. INTRODUCTION AND BACKGROUND.

According to the Environmental Protection Agency (EPA) Air Quality Criteria for Nitrogen Oxides (Booklet AP-84), the important oxides in terms of nitrogen are nitrogen dioxide (NO_2) and nitric oxide (NO). These oxides are usually monitored simultaneously using a single instrument which passes both compounds through an oxidizer and reports the NO_2 given as total oxides of nitrogen (NO_x). The oxidizers commonly used are aqueous potassium permanganate ($KMnO_4$)[1,2] or chromium trioxide (CrO_3)[3,4,5] adsorbed on a solid support. Both oxidizers have limitations. The permanganate solution removes some NO_2 ($2NO_2 + H_2O \rightarrow HNO_3 + HNO_2$) from the air sample, thus reducing the actual amount measured.

1. $2NO + O_2 \rightarrow 2NO_2$ (measured)
2. $NO + O_2 \rightleftharpoons NO_3$ (not measured)
3. $NO_3 + NO \rightarrow 2NO_2$ (measured)
4. $2NO_2 + H_2O \rightarrow HNO_3 + HNO_2$ (not measured)

Proof of this NO_2^- to NO_3^- oxidation may be found by analyzing the permanganate solution for nitrates. The chromium trioxide/solid support

system absorbs moisture during periods of high relative humidity (above 50%), thereby reducing oxidizer efficiency.

After the oxidation procedure, the analysis may follow either the Saltzman[6] or the Jacobs-Hochheiser[7] methodology. It has been recently reported that the collection efficiencies for NO_2 are remarkably increased in the Hochheiser method by the addition of small amounts of a "proton source", that is, a compound containing reactive hydrogen atoms in the molecule[8]. Some of the compounds examined were 1-amino naphthalene, 1-naphthyl ethylene diamine, 1-naphthol, and the "R-salt" (2-naphthol-3,6-disulfonic acid disodium salt). Indications are that the addition of "R-salt" and/or triethanolamine improve reagent stability for the Hochheiser procedure. This modification of the Hochheiser procedure was applied to the Saltzman method by our laboratory.

Owing to the limitations found when using the published NO_x methods, a two monitor system has been developed, with one station monitoring nitrogen dioxide and the other nitric oxide. The NO_2 monitor used is the Technicon® Air Monitor IIA, which employs the Lyshkow[9] modification of the Saltzman method. This modification has the "R-salt" as a component of the reagent. The reagent was further modified by our laboratory by adding 0.2% triethanolamine. The nitric oxide is monitored using a modified Technican IIA. Our modification removes NO_2, by absorbance,

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from the air being sampled. The use of the absorbance column was initially conceived by Lavaggi[10, 11] who attached a simular column to a bubbler and used manual analytical procedures. In addition to the modifications which were made on Lavaggi's column packing and column conditioning procedures, in our modification the unabsorbed NO is passed through the NO_2 absorbing column and bubbled through an acidified potassium permanganate solution and oxidized to nitrogen dioxide, which subsequently is measured automatically.

II EXPERIMENTAL.

A. METHOD:

1. Field Phase - All tests were conducted in the field using ambient stations equipped with Technicon Air Monitor II A's having manifolds for NO_2 (Figures 1 and 2). Measured samples of NO and/or NO_2 in Mylar® bags (150 - 400 liters) were diluted to ambient concentrations using nitrogen or dry zero air. The pollutant gas or gases were injected with a microliter (ul) syringe (10 ul to 50 ul size) through a rubber septum (point T on Figure 3). The NO/NO_2 samples were diluted in the Mylar Bags (Figure 3) as follows. The bag was filled to one half volume and the pollutant injected. The bag was then filled to the desired volume.

Example

250 liter bag
50 ul NO
30 ul NO_2

$\frac{50 \text{ ul NO}}{250 \text{ l } N_2}$ = conc. of NO = 0.2 ppm NO

30 ul (N_2O_4- NO_2) x 1.7 (factor due to dimer)
= 51 ul NO_2

$\frac{51 \text{ ul } NO_2}{250 \text{ l } N_2}$ = 0.2 ppm NO_2

Both monitors were calibrated for NO_2 using a sodium nitrite standard and the sampling flow rate was set using a wet test meter. Due to the high concentrations of NO expected, the sensitivity of the NO monitor was decreased by exchanging the 50 mm flowcell with a 15 mm flowcell. This resulted in a working range of 0 to 0.6 ppm. The Mylar bags containing the gaseous standards were connected to both instruments through the use of a three-way glass "T" connection (Figure 4). Use of this standardization procedure permitted independent monitoring for both gases (NO/NO_2) and provided the capability of detecting any photochemical oxidation taking place during the test procedure. In order to evaluate the NO_2 removal capabilities of the triethanolamine column (Figure 5), an air monitor with the 20 percent triethanolamine column modification was connected to a bag containing a high concentration of NO_2 (Table 1, Test #1 and Figure 5). Once this had been demonstrated, a bubbler containing a potassium permanganate/sulfuric acid solution was added to complete the NO system. Several bubbler configurations were evaluated, one which was discarded called for filling

the bubbler half full of permanganate solution. This resulted in an unacceptable oxidation efficiency of 45% (Figure 6). The modification finally adopted called for filling the bubbler to three-quarters of its height with No. 3000 - 6 mm glass beads, and next adding fifty milliliters of the permanganate solution. This type of bubbler design not only gave good reagent to sample contact, but also prevented excessive splashing. Figures 6 and 7 show representative recorder charts of the data obtained in field. Table 1 gives the results and collection efficiencies of the standardization tests done in the field.

2. Laboratory Phase - Further NO oxidation studies were completed during the laboratory phase. The sample bags were prepared, diluted and attached to the air monitors in the same manner as in the field operations. The following method developments were listed and studied.

a. To evaluate the Lavaggi method for the preparation of the chromium trioxide/solid support oxidation columns.

b. To compare the oxidation efficiency of the oxidants CrO_3 and $KMnO_4$.

c. To check, under continuous flow analysis, the physical and chemical change of the CrO_3 which was apparent when moisture laden air came in contact with the oxidant column. The CrO_3 columns made and used by the states of New York and California were moisture treated until the pink-brown color of the dried CrO_3 turned yellow-orange. This color change appeared after a moisture treatment of one-half hour.

d. To develop systems that had ease of reagent handling and monitor connection for field use.

e. To continue the laboratory phase and try new oxidation methods, such as ozone production and/or a method to heat the CrO_3 tube so that air samples with high relative humidities could be monitored.

The laboratory phase of investigations provided answers to some of the preceding methodology questions. Where it is possible, figures of actual chart recordings support the findings. The preparation of the triethanolamine (TEA) column packing was modified. Previously, the TEA was dissolved in water and placed on the solid support. The excess TEA was decanted and the TEA/solid support dried. This method of preparation did not give a true 20% w/w liquid phase absorbed on the solid support. The preparation was changed (see reagent section). The CrO_3 packing gave the best oxidation efficiency when used dry, thus, moisture pre-conditioning was not necessary and if used, depleted the oxidant (Figures 9, 10 and 11). When moisture was added to the air sample, the chart deflection could be mistaken as an increase in oxidation efficiency. With further studies on the moisture addition, the following results were found. First, with a continuous moisture addition, the oxidation ability of the CrO_3 column diminished (Figure 12). Next, when moisture was added over 15-minute time spans and then removed, the chart recorded a down-scale swing and then returned to the original NO_2 plateau (Figure 13).

Future laboratory studies are planned to utilize an ozone oxidation system or to develop an oxidation column heater which should enable the CrO_3/solid support system to be used at higher relative humidities. With these studies we hope to produce an oxidation system which would have good field capabilities.

B. REAGENTS.

Saltzman Reagent - 20 liters

Chemical	Technicon	Modified
Distilled water	20 l	20 l
Tartaric acid	300 gm	300 gm
Sulfanilimide	30 gm	30 gm
N-(1-naphthyl)ethylene diamine Hcl	3 gm	3 gm
2-naphthol-3,6-disulfonic acid	1 gm	1 gm
Triethanolamine	--	40 ml

Potassium Permanganate

a.	Distilled water	96 ml
b.	Potassium permanganate	2 gm
c.	Sulfuric acid (conc.)	2 ml

The reagent was placed into the bead-packed bubbler as described earlier and connected to the Monitor IIA. This oxidation system was used both with and without the triethanolamine tube.

Tube preparation:

Triethanolamine Tubes: 20 grams triethanolamine are dissolved in 300 ml of reagent grade acetone. To this is added 100 grams of 30/60 mesh chromosorb® P. The mixture is stirred continuously while the acetone is boiled off using a steam bath. The heating is continued

overnight to remove all of the acetone. 1/2" x 6" polyethylene tubes with one end plugged with glass wool are filled to a height of 5 1/2", and the open end is plugged with glass wool. Dry air is then blown through the tube for 30 - 60 seconds to settle the tube packing and remove the last traces of acetone.

Chromium Trioxide Tubes: Dissolve 20 grams of CrO_3 in 100 ml of distilled water. Add the 20% aqueous solution of chromium trioxide to crushed firebricks (30/60 mesh). Allow to stand 30 minutes with occasional stirring. Decant the excess fluid and place the resultant slurry in a drying oven set at 105°C for four hours. Allow the dry coated firebrick to cool, bottle and cap the cooled firebrick and tape the mouth of the bottle to insure they're being airtight. The 1/2" x 6" tubes are the same type used with the triethanolamine and are prepared in the same fashion.

C. FINDINGS.

1. Both oxidation systems worked well and gave recovery effiencies of 75 to 80 percent.

2. The two monitor system had the best recovery efficiency and would not lose the concentration of NO_2 because of further oxidation.

3. The triethanolamine-crushed firebrick tube demonstrated good removal of the nitrogen dioxide without interfering with the nitric oxide concentration.

4. Further laboratory studies are now in progress to find an efficient way of heating the CrO tube, thus allowing its use at higher relative humidities.

5. The average overall efficiency of the NO system is 75%.

6. The monitors checked cross-checked well against a source (stack) NO_x monitor. (Table 2)

D. CONCLUSIONS.

1. There are now continuous automated methods available to analyze the oxides of nitrogen (NO, NO_2) at high relative humidities.

2. Selection of the oxidant system should be made to concur with the relative humidity of the survey site.

3. The triethanolamine modified reagent gave a better collection efficiency and faster rate of color development.

4. Preference was given to the chromium trioxide tube because of the ease of in handling during monitor connections.

5. The use of the Monitor IIA for the analysis of the oxides of nitrogen is at the "state of the art" until better oxidation systems can be developed.

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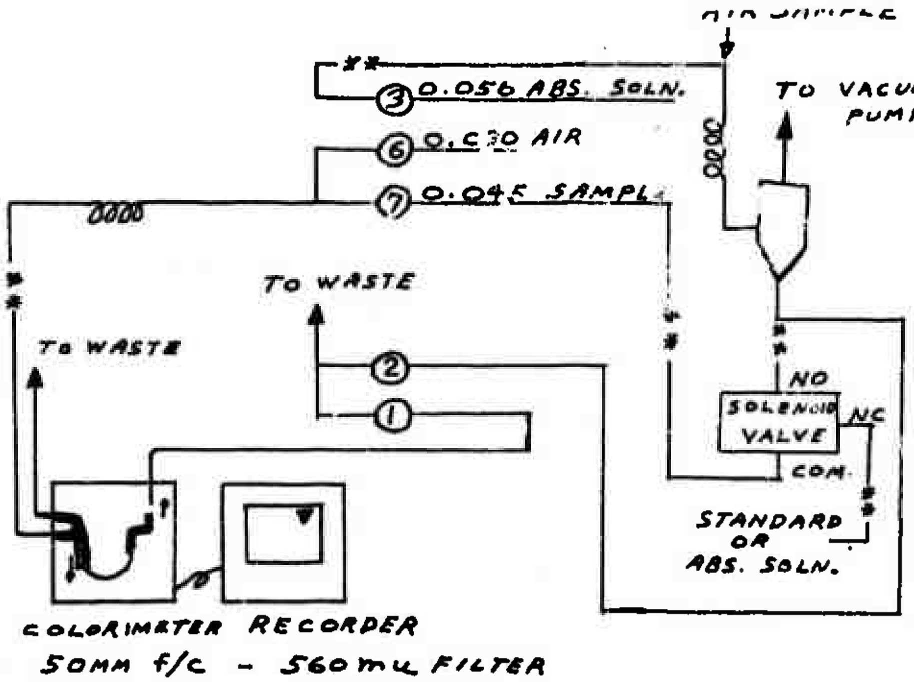
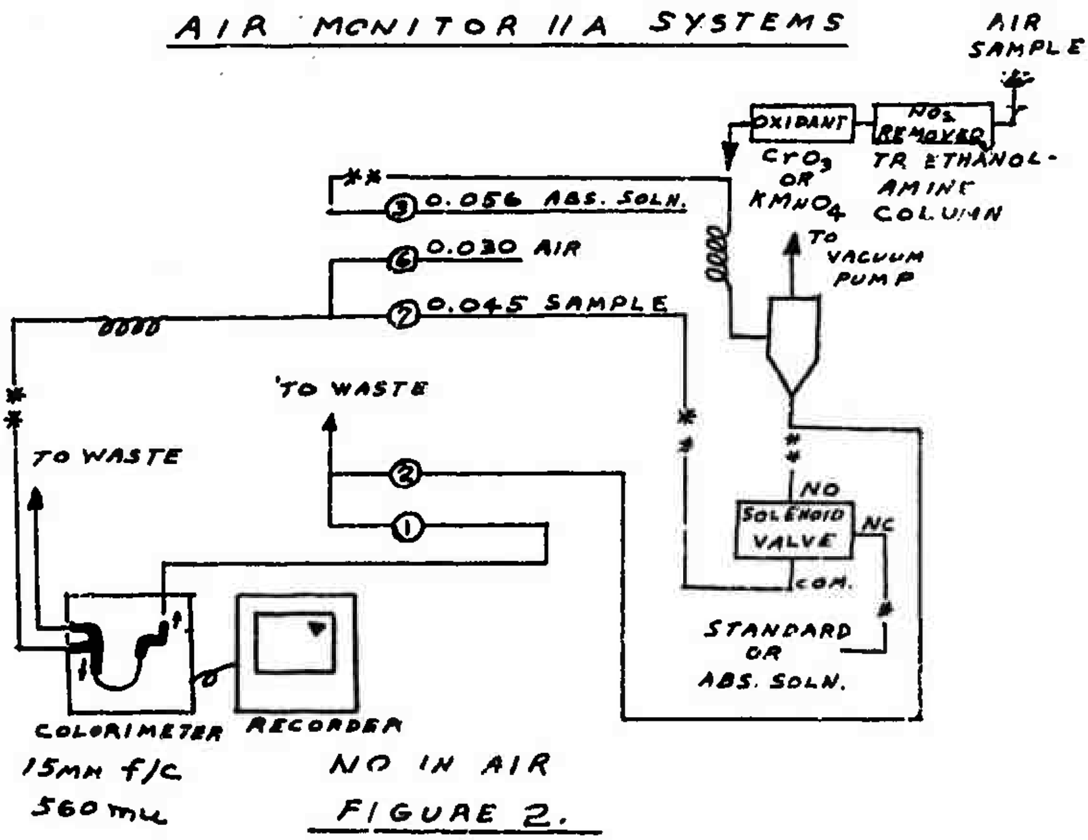


NO_2 IN AIR

FIGURE 1.

AIR MONITOR IIA SYSTEMS



NO IN AIR

FIGURE 2.

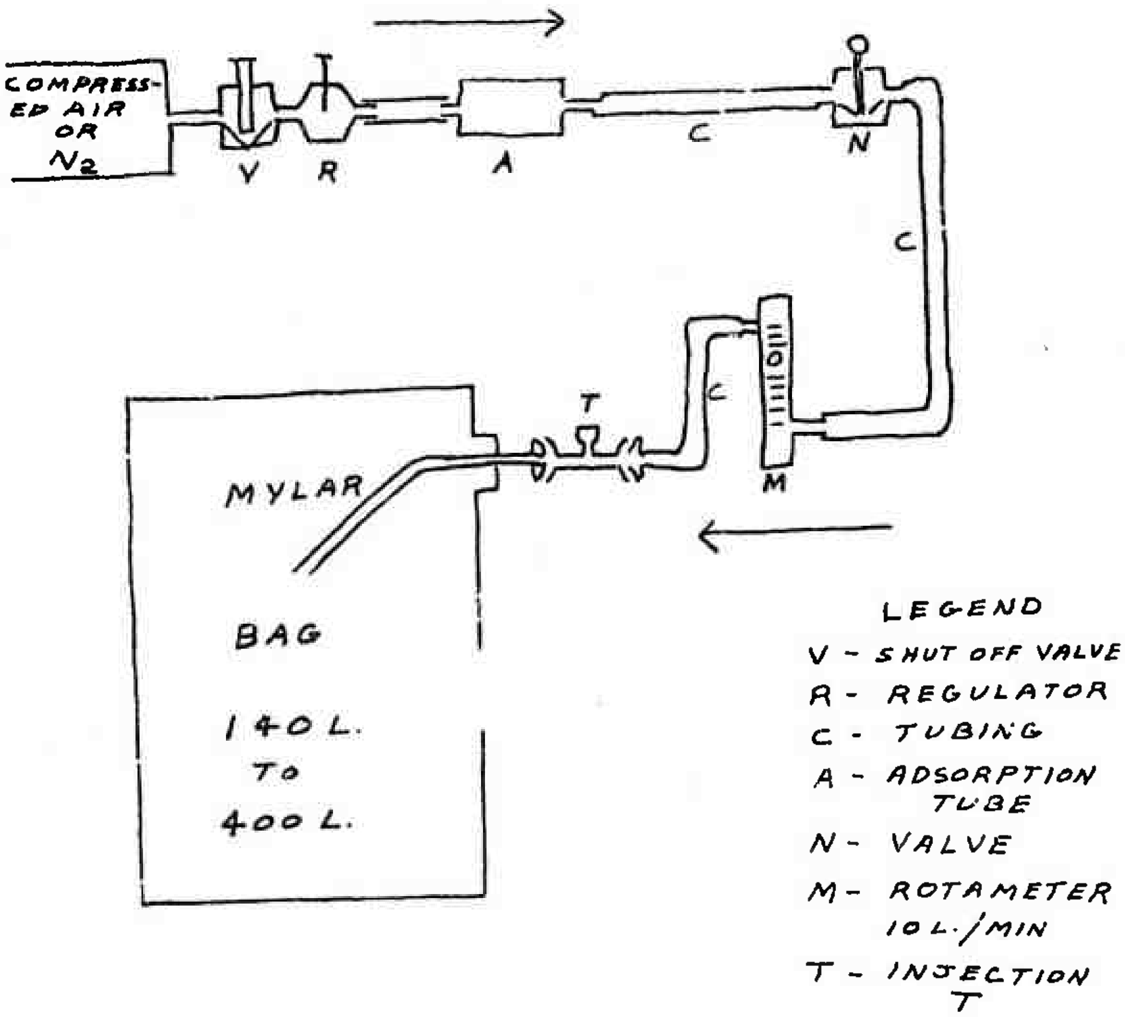


FIGURE 3. - SYSTEM FOR FILLING MYLAR SAMPLE BAG

TECHNICON AIR MONITOR II A

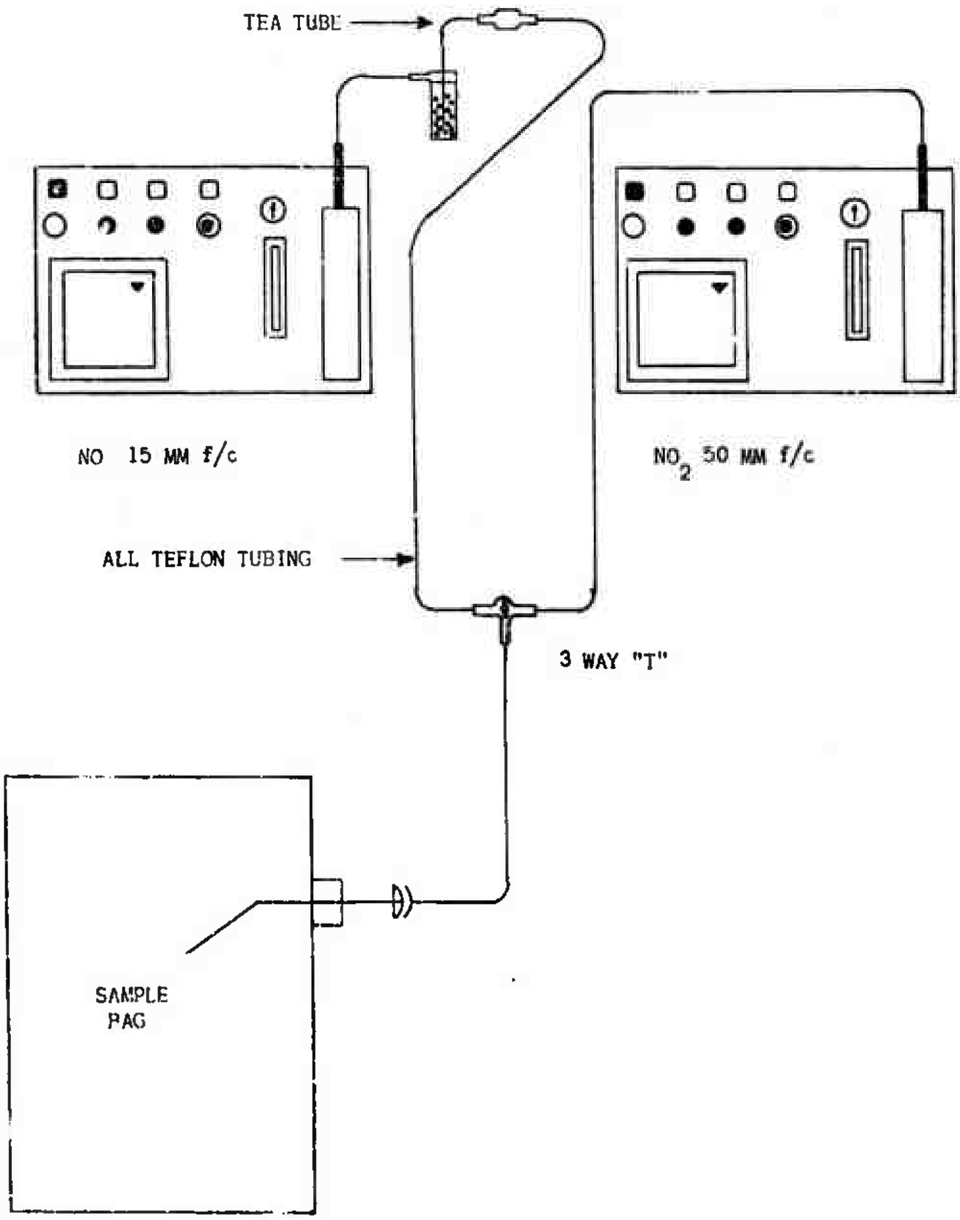
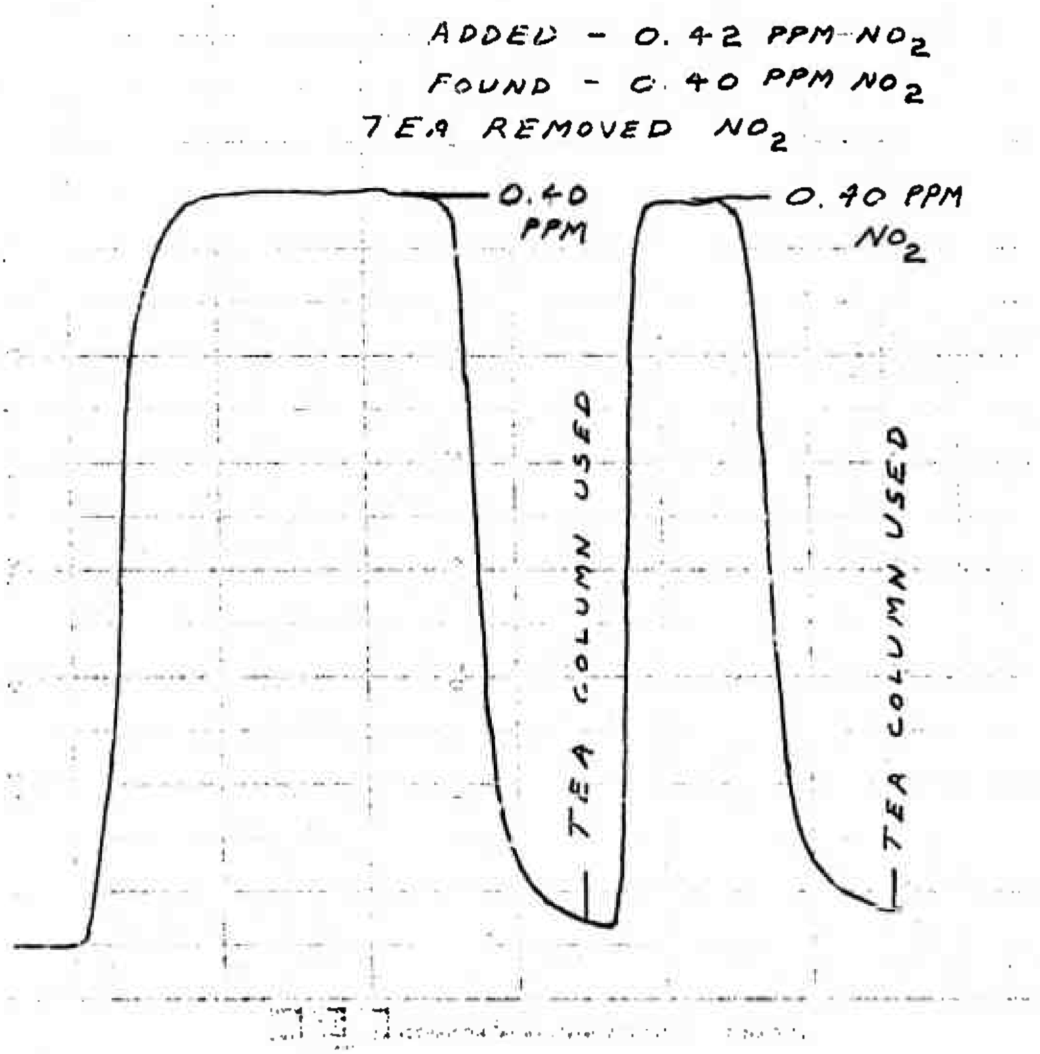


FIGURE 4.



REMOVAL OF NO_2 WITH TRIETHANOLAMINE (TEA)

FIGURE 5.

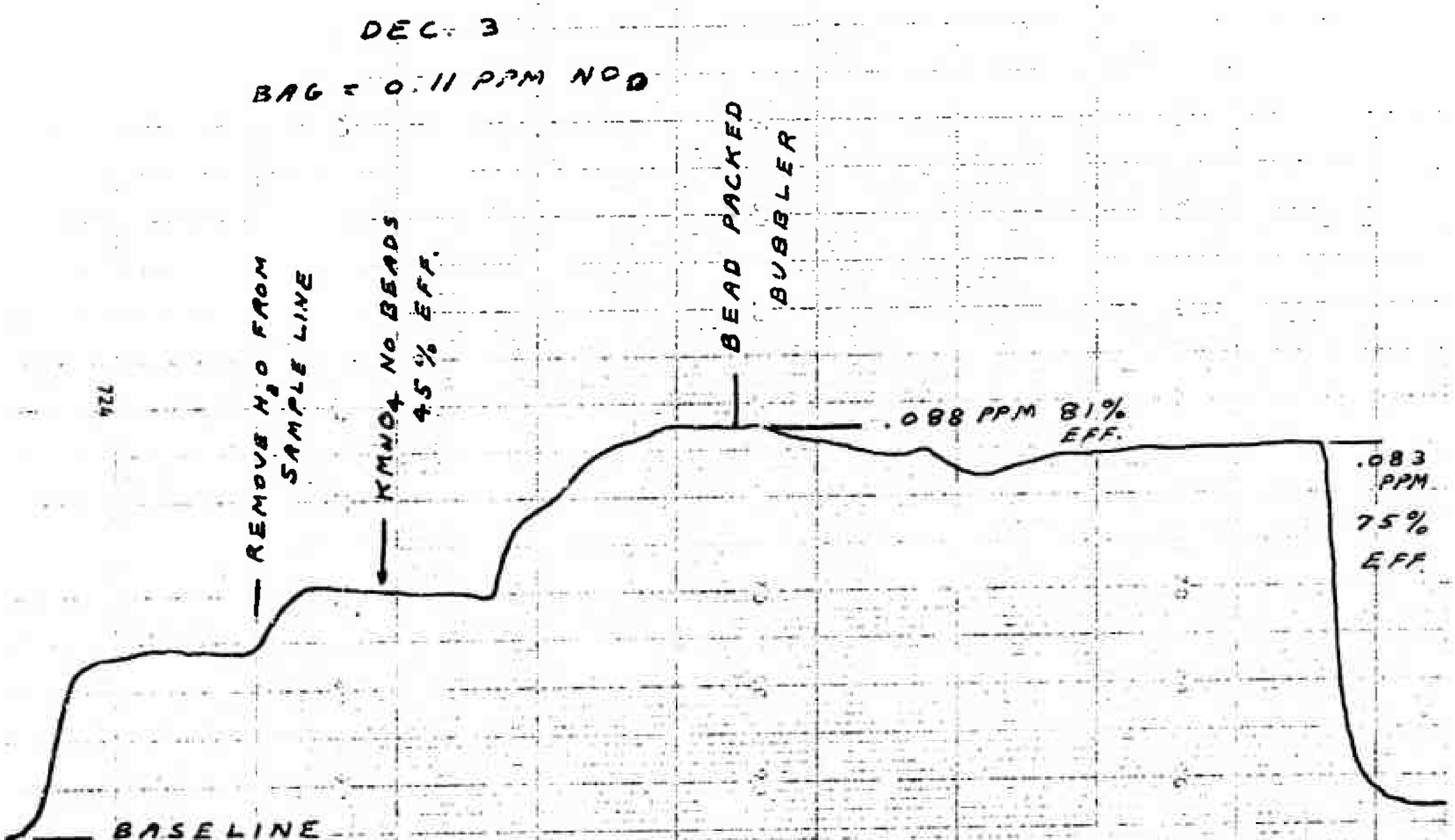

DEC. 3
BAG = 0.11 PPM NO_2
REMOVE H_2O FROM SAMPLE LINE
$KMnO_4$ NO BEADS 45% EFF.
BEAD PACKED BUBBLER
.088 PPM 81% EFF.
.083 PPM 75% EFF.
BASELINE

FIGURE 6.

FIGURE 7.

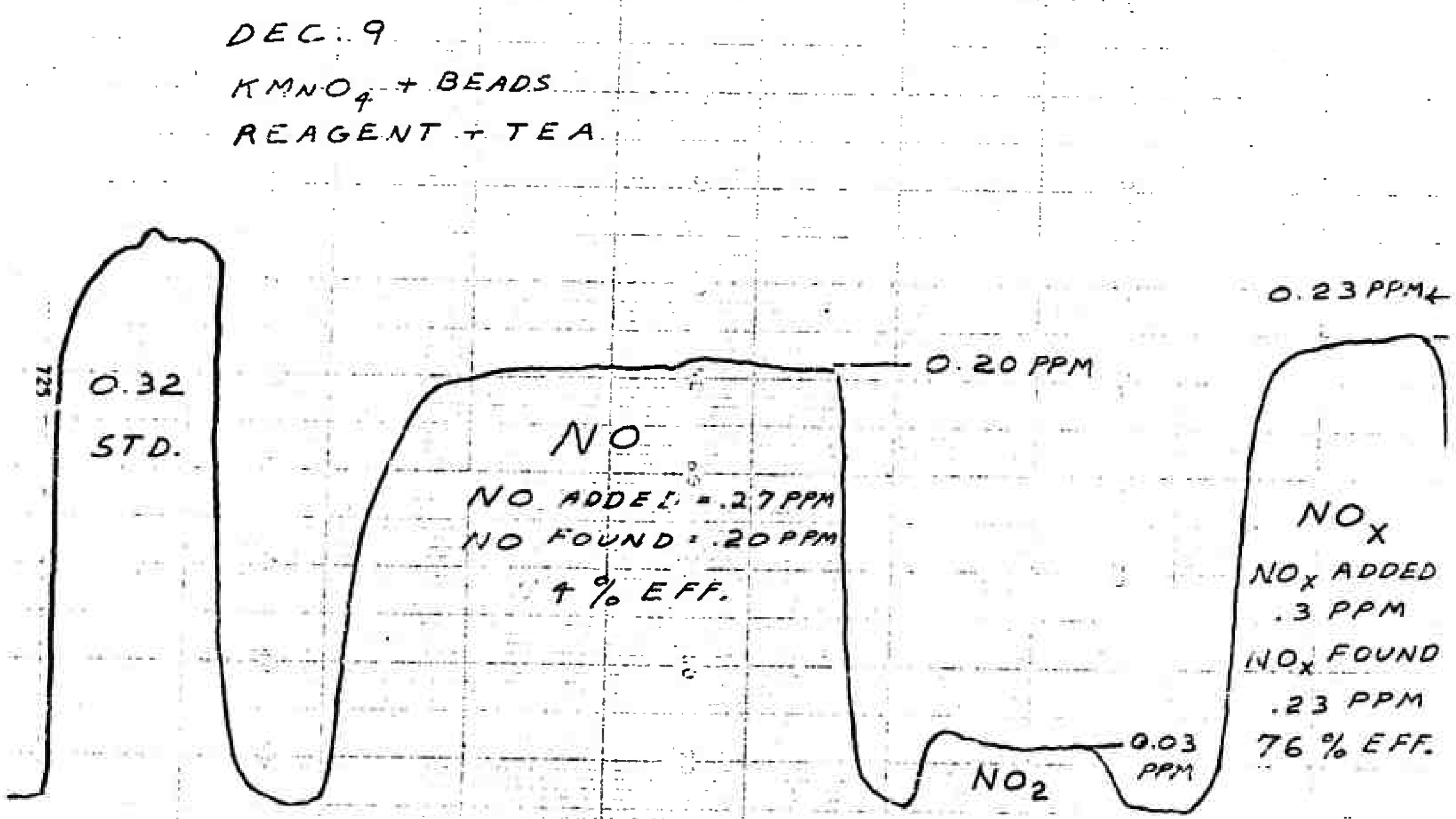

DEC. 9
$KMnO_4$ + BEADS
REAGENT + TEA
725
0.32
STD.
NO
NO ADDED = .27 PPM
NO FOUND = .20 PPM
4 % EFF.
0.20 PPM
NO_2
0.03 PPM
0.23 PPM
NO_x
NO_x ADDED
.3 PPM
NO_x FOUND
.23 PPM
76 % EFF.

TABLE 1

STANDARDIZATION TESTING OF NO, NO , NO MONITOR SYSTEMS

Test No.	Date	Length of Test	Conc. of Bag NO_2 ppm	Conc. of Bag NO ppm	Conc. of Bag NO_x ppm	Test Results NO_2 ppm	Test Results NO ppm	Test Results NO_x ppm	System Efficiency NO_2 %	System Efficiency NO %	System Efficiency NO_x %
#1 Efficiency of $N(CH_2-CH_2OH)_3$ Triethanolamine scrubber on NO_2 removal	30 Nov 71	3 hrs	#1 - 0.42			#1 - 0.40 0.00 0.40 0.00			#1 - 90% eff. The NO_2 (TEA) = 100 eff.		
#2 NO bag	1 Dec 71										
#3 NO bag	2 Dec 71	3 hrs	#1 - 0.5 #2 - 0.5			#1 - .096 #2 - .18			#2 - $KMNO_4$ - 45% eff.		
#4 (1) Try midget impinger (2) Try packed glass impinger	3 Dec 71	5-1/2 hrs		.11			#1 - .05 #2 - .085		#1 - 45% eff. #2 - Packed glass - 75 to 80% eff.		
#5 Mixed bag NO_2 + NO in N_2	4 Dec 71	3-1/2 hrs	0.70	0.30	0.40	0.085	0.13	0.10	85	43	25

Test No.	Date	Length of Test	Conc. of Bag NO_2 ppm	Conc. of Bag NO ppm	Conc. of Bag NO_x ppm	Test Results NO_2 ppm	Test Results NO ppm	Test Results NO_x ppm	System Efficiency NO_2 %	System Efficiency NO %	System Efficiency NO_x %
#6 Mixed bag NO_2 + NO in N_2	5 Dec 71 a.m.	3 hrs	0.085	0.25		0.065	0.13		77	54	
#7 Mixed bag NO_2 + NO in N_2	5 Dec 71 p.m.	1 hr	0.056	0.30		0.06	0.12		100	40	
#8 Mixed bag NO_2 - NO in N_2	6 Dec 71	6 hrs	0.10	0.22		0.11	0.16		100	73	
#9 NO bag NO N_2	7 Dec 71	6 hrs					0.09			50	
#10 NO bag NO in N_2	8 Dec 71 a.m.	3 hrs	0.3				0.13			43	
#11 NO bag NO in N_2	8 Dec 71 p.m.	3 hrs		0.15			#1 - 0.085 #2 - 0.11*			57 75	

* TEA used in reagent

Test No.	Date	Length of Test	Conc. of Bag NO_2 ppm	Conc. of Bag NO ppm	Conc. of Bag NO_x ppm	Test Results NO_2 ppm	Test Results NO ppm	Test Results NO_x ppm	System Efficiency NO_2 %	System Efficiency NO %	System Efficiency NO_x %
#12 Liquid Standard (LS) + NO bag NO in N_2	9 Dec 71	6 hrs	LS = 0.32	0.3		LS #1 - 0.26 #2 - 0.28	#1 - 0.12 #2 - 0.20		Liquid 81 87	40 67*	
#13 NO_2 in N_2	10 Dec 71	5 hrs	#1 - 0.26 #2 - 0.26				#1 - 0.13 #2 - 0.22		50 86*		
#14 Mixed bag NO_2 - NO in N_2	11 Dec 71	3 hrs	0.11	0.17	0.28	0.105	0.11	0.17	95	65*	61
#15 Mixed bag NO_2 + NO in N_2	12 Dec 71	3-1/2 hrs	0.04	0.105	0.145	0.05	0.09 to 0.105		100	90* to 100	
#16 Mixed bag NO_2 + NO in air	13 Dec 71	4 hrs	0.038	0.10		#1 - 0.04 #2 - 0.025	0.075		#1 - 100* #2 - 62	75*	

* TEA used in reagent

Test No.	Date	Length of Test	Conc. of Bag NO_2 ppm	Conc. of Bag NO ppm	Conc. of Bag NO_x ppm	Test Results NO_2 ppm	Test Results NO ppm	Test Results NO_x ppm	System Efficiency NO_2 %	System Efficiency NO %	System Efficiency NO_x %
#17 Engine Exhaust	14 Dec 71	Poor Sample - No Results									
#18 Engine Exhaust	15 Dec 71		50 ml of stack gas - Diluted with 150 liters of air or 0.32 ppm NO_x			0.105	0.10	0.205	64% of the stack gas conc.		

1. $N(CH_2-CH_2-OH)_3$ or TEA gave efficiencies of 65% or better in all six tests in which it was used.

2. Reagent without TEA gave efficiencies of 65% or better in 2 out of 9 tests.

APRIL 12, 1972 - LAB.

NO

NO_2 REMOVED BY

TEA TUBE

BAG = .10 PPM NO_2

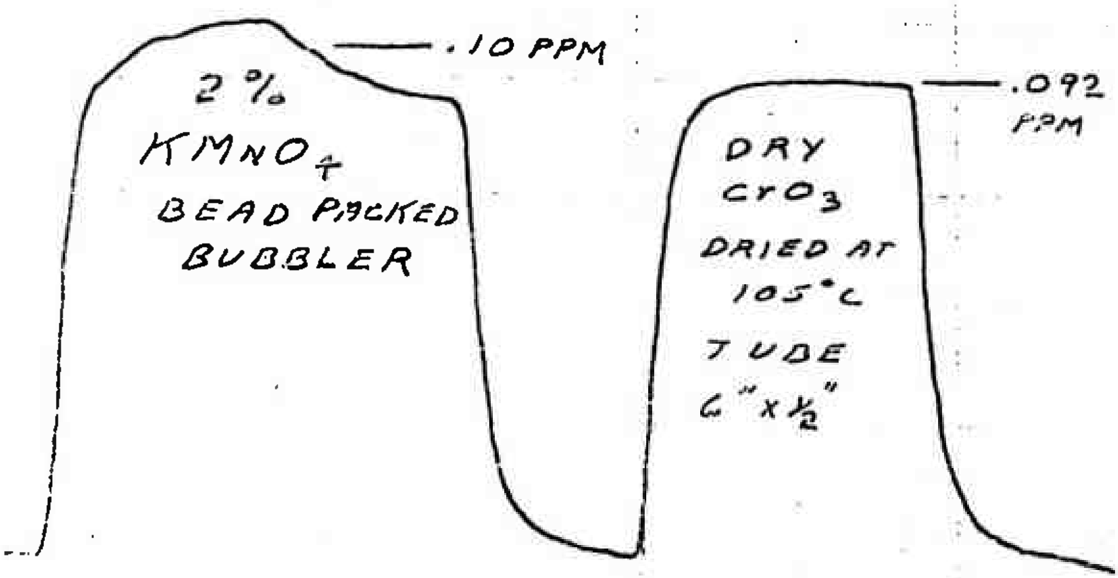


FIGURE 8.

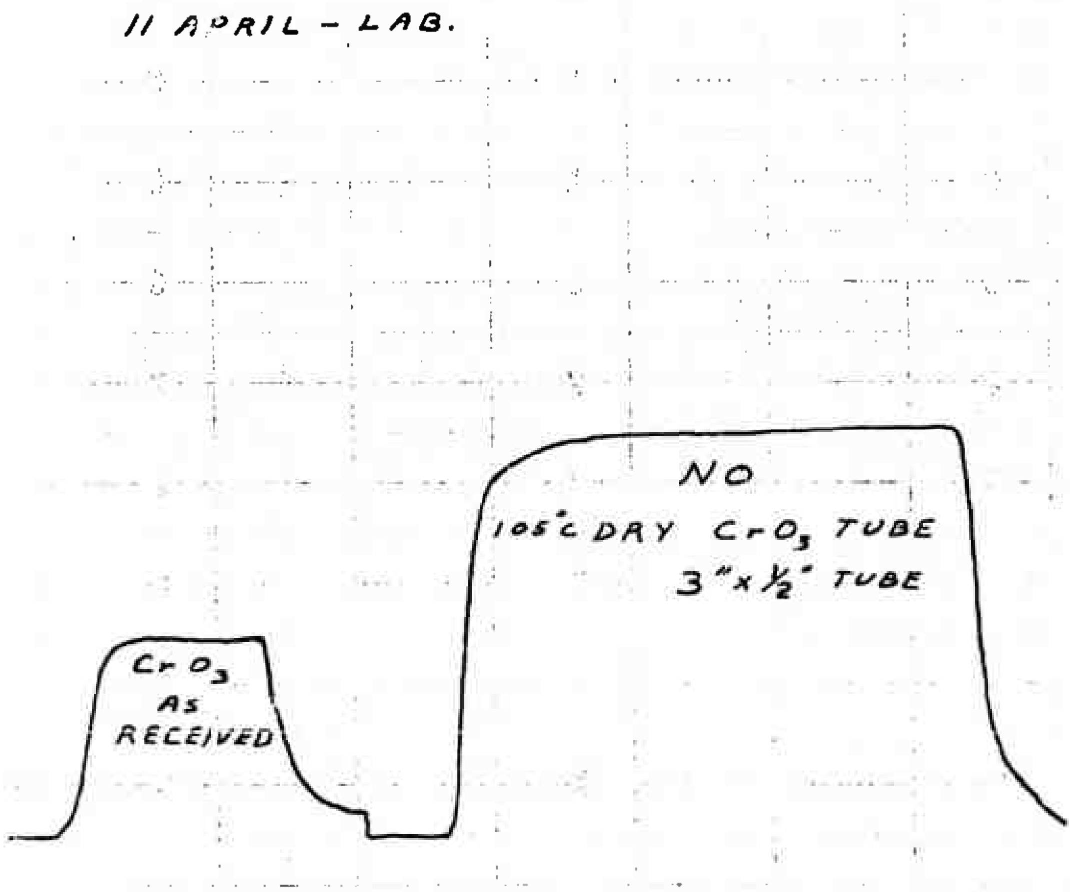


FIGURE 9.

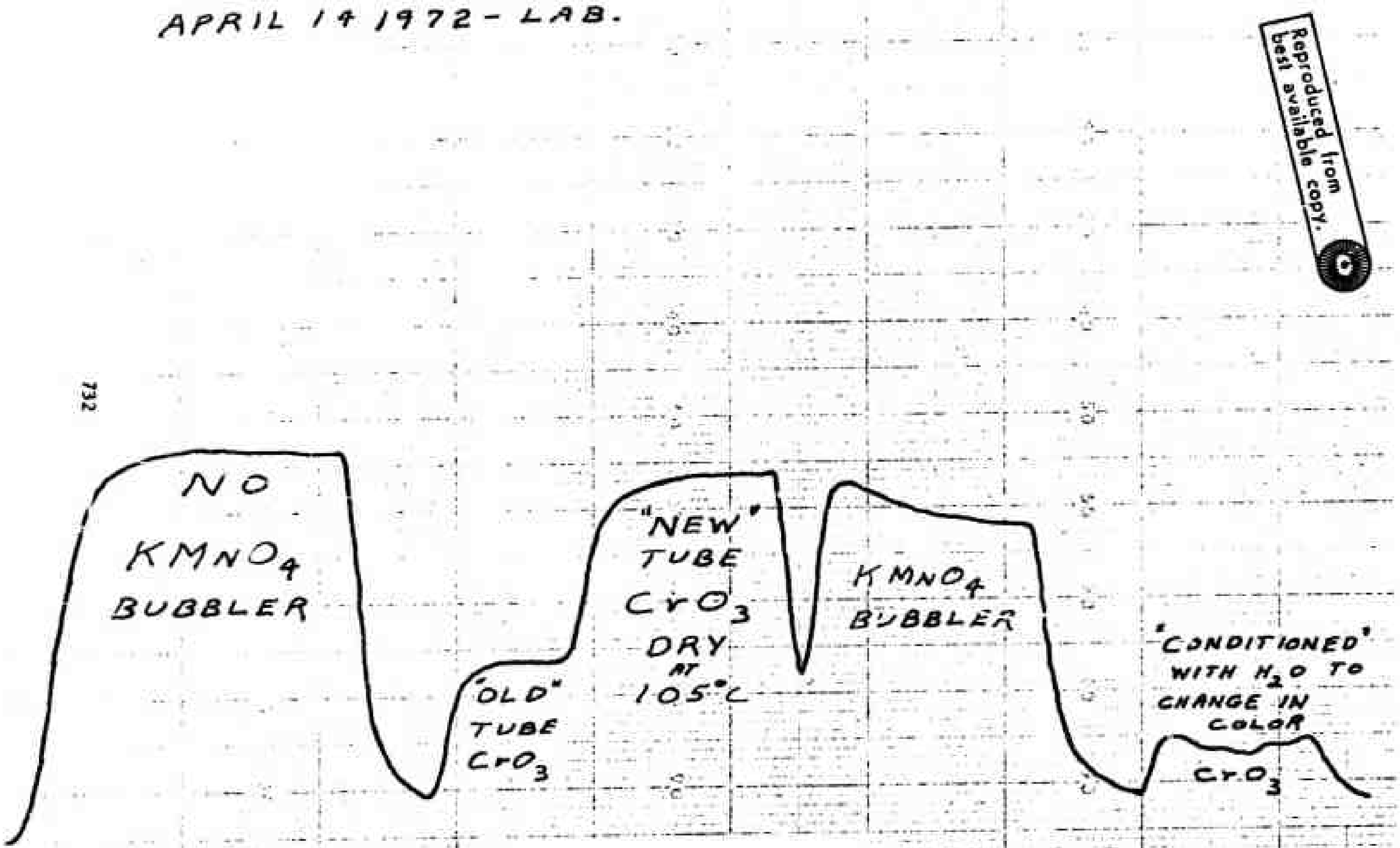

APRIL 14 1972 - LAB.
NO KMNO4 BUBBLER
"OLD" TUBE CrO3
"NEW" TUBE CrO3 DRY AT 105°C
KMNO4 BUBBLER
"CONDITIONED" WITH H2O TO CHANGE IN COLOR
CrO3

FIGURE 10.

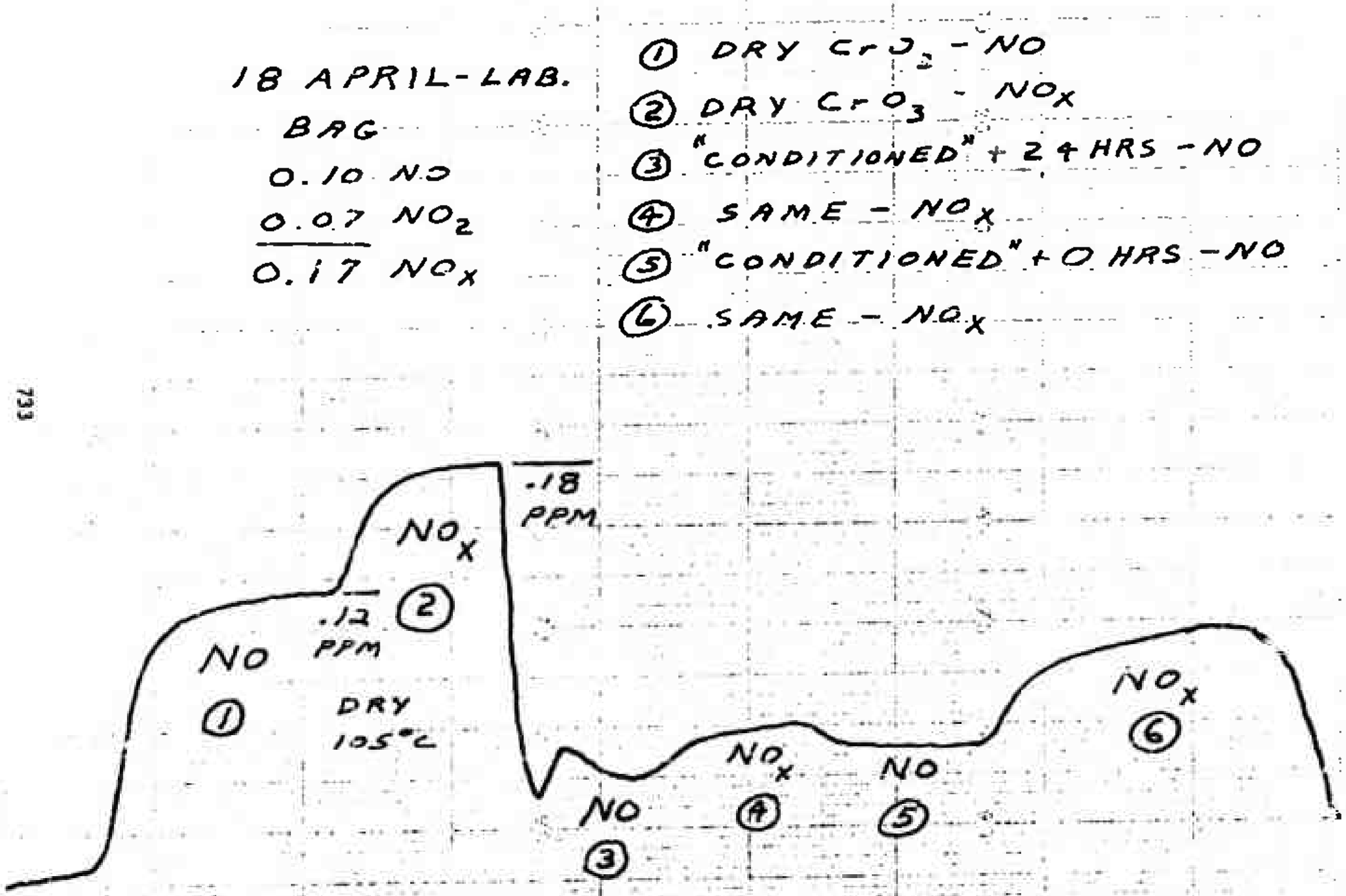

18 APRIL-LAB.
BAG
0.10 NO
0.07 NO_2
0.17 NO_x
① DRY CrO_3 - NO
② DRY CrO_3 - NO_x
③ "CONDITIONED" + 24 HRS - NO
④ SAME - NO_x
⑤ "CONDITIONED" + 0 HRS - NO
⑥ SAME - NO_x
.18 PPM
.12 PPM
NO ①
NO_x ②
DRY 105°C
NO ③
NO_x ④
NO ⑤
NO_x ⑥

FIGURE 11

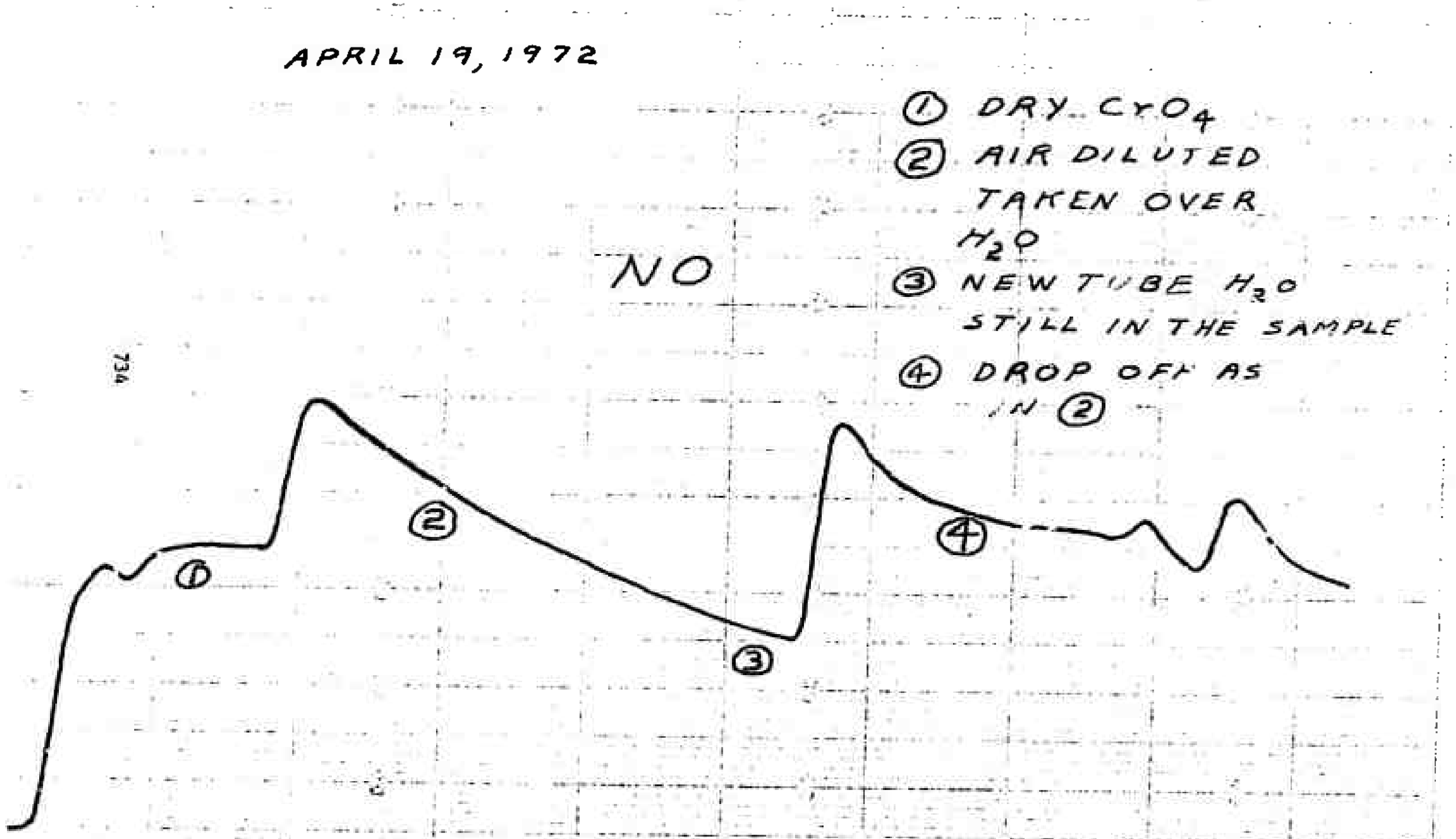

APRIL 19, 1972
NO
1 DRY CrO_4
2 AIR DILUTED TAKEN OVER H_2O
3 NEW TUBE H_2O STILL IN THE SAMPLE
4 DROP OFF AS IN 2
1
2
3
4

FIGURE 12.

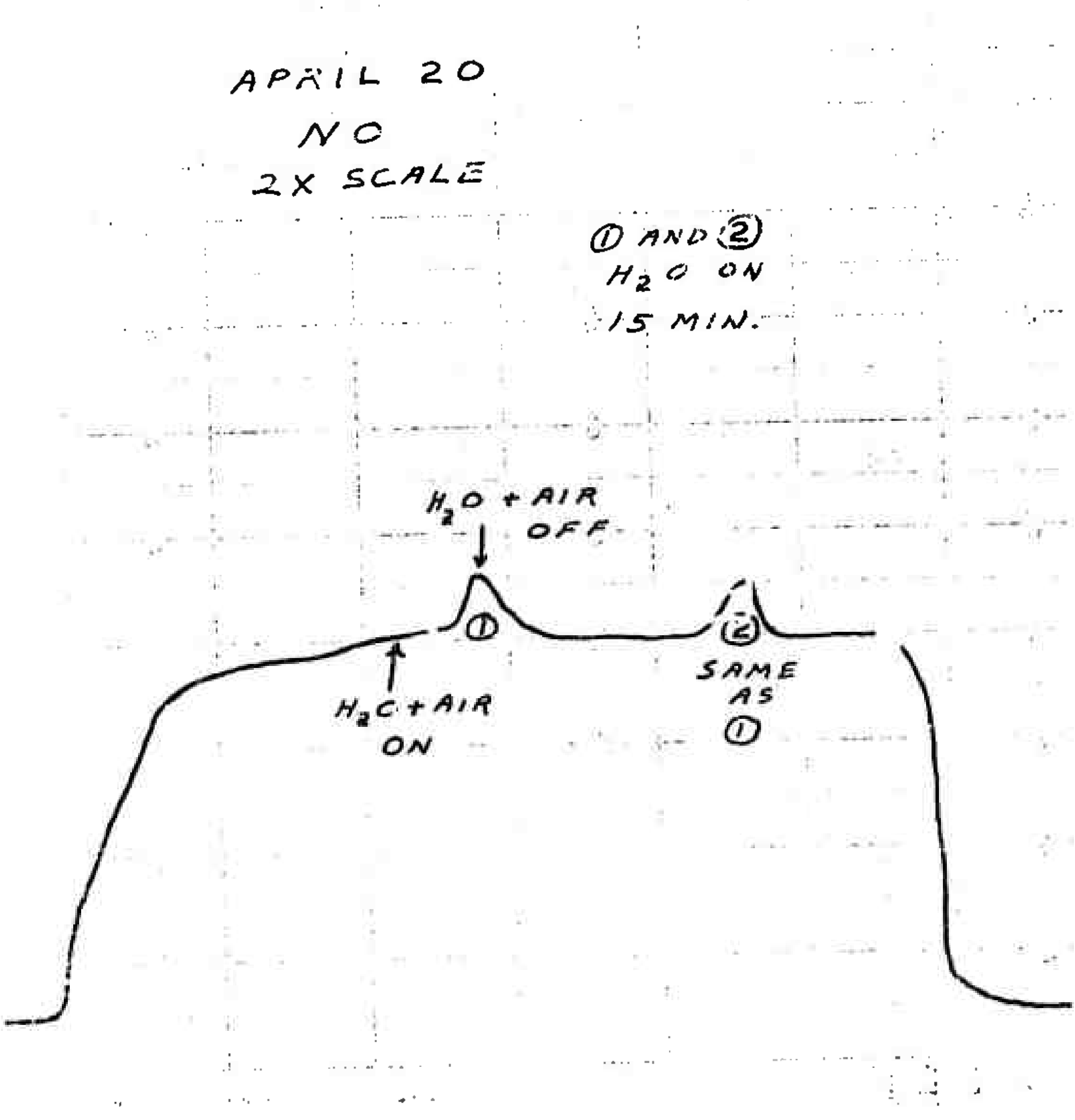

APRIL 20
NO
2X SCALE
① AND ②
H2O ON
15 MIN.
H2O + AIR
OFF
①
②
SAME
AS
①
H2C + AIR
ON

FIGURE 13.

TABLE 2
TESTING OF DIESEL STACK EMISSIONS FOR NO_x

Test No.	Date	Length of Test	Conc. of Bag NO_2 ppm	Conc. of Bag NO ppm	Conc. of Bag NO_x ppm	Test Results NO_2 ppm	Test Results NO ppm	Test Results NO_x ppm	System Efficiency at 65% Conv. of NO - NO_2	System Efficiency at 75% Conv. of NO - NO_2	% Return
#1 50 ml exhaust in 140 l (air)	17 Jan 72	1 hr			0.36	0.05	0.28	0.33	92%		92%
#2	17 Jan 72	1 hr			0.36	0.06	0.22	0.28	78%		78%
#3	17 Jan 72	1 hr			0.36	0.06	0.20	0.26	72%		72%
#4	17 Jan 72	1 hr			0.36	0.06	0.39	0.45	125%		125%
#5 20 ml exhaust in 140 l (air)	18 Jan 72	1 hr			0.14	0.04 0.04	0.07 0.08	0.11 0.12	86%	79%	86% 79%
#6	18 Jan 72	1 hr			0.14	0.04 0.04	0.08 0.09	0.12 0.13	93%	86%	93% 86%
#7	18 Jan 72	1 hr			0.14	0.04 0.04	0.10 0.12	0.14 0.16	114%	100%	100% 114%

AN OVERVIEW OF THE RECOMMENDED INSTRUMENT SAFETY GUIDE FOR MELT/POUR PLANTS

by

Guy Adams, Honeywell Inc.*

and

Louis Jablansky, Picatinny Arsenal**

This paper covers the background, rationale, some of the content and the basis of the Instrument Safety Guide which was prepared during the Instrument Safety Standards Program. The figures in the paper are reproduced from the slides used for the oral presentation.

Introduction

Extensive automation of present-day Army munition plants is planned as part of the Army Munitions Plant Modernization Program, in which Honeywell Inc. is playing a key role. A major obstacle to the modernization program, however, was brought to light in a funded Melt/Pour study by Honeywell -- existing instrument safety rules could make procurement of the many sensing instruments required for plant automation costly, difficult or, in some cases, impossible.

This finding led to the Instrument Safety Standards Program with a major objective of preparing an Instrument Safety Guide for Melt/Pour Plants based on the most up-to-date information available. Data was gathered on present safety codes, explosives initiation, past accident records and initiation energy sources through a literature review and by numerous personal contacts. This data was then catalogued and evaluated for potential use in the safety guide, and recommendations were made on experiments needed to improve the initiation data base.

The end product of this study was a two-volume final report, Volume I containing the basic documentation and Volume II a recommended Instrument Safety Guide (rISG). The rISG, it is hoped, will be a significant step in improving instrument safety standards.

Interview Results

A number of discussions were held with instrumentation engineers and explosive initiation and safety experts whose opinions are summarized in Figure I.

OPINIONS OF PERSONS INTERVIEWED

- NO INSTANCES ON RECORD OF ACCIDENTS DUE TO INSTRUMENTS
- LARGE SPARK ENERGY REQUIRED TO INITIATE SECONDARY EXPLOSIVES.
- ELECTRICAL INSTRUMENTS ARE NOT HAZARDOUS
- AGREEMENT ON THERMAL INITIATION.
- PRESENT SAFETY PRACTICE IS TOO CONSERVATIVE
- NEW NATIONAL (INTRINSIC) SAFETY CODE NEEDED

Figure 1

Significantly there is not a single instance on record of any accident in any industry, including the munitions industry, caused by an instrument malfunction. Very large spark energies are required in electric spark tests to initiate secondary explosives. Consequently, initiation experts believe that electrical instruments are not a significant hazard in secondary explosives.

There is wide agreement that the underlying cause of explosives initiation is thermal initiation, meaning the initiation is caused by a hot spot due to local heating or energy dissipation.

General agreement was found that the present explosives safety practices are too conservative and that a new safety code based on intrinsic safety is needed. There was limited opposition to this view by a few

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*Guy Adams is a member of the Honeywell Corporate Program Center. This organization was established in 1969 to focus the diverse capabilities of Honeywell on the Munitions Plant Modernization Program. This paper is from a final report on a funded contract, the Instrument Safety Standards Program, under the direction of Louis Jablansky of the Chemical Process Technology Division, Manufacturing Technology Directorate, of Picatinny Arsenal. Mr. Jablansky is co-author of this paper.

persons who believe that (a) past practice does not need to be changed because it is sufficiently safe and because instruments can be obtained with the restrictions it imposes and (b) that the munitions industry is too small to warrant coverage by a national safety code. The consensus, however, was that present safety practice is outdated, too conservative, and that a new safety code is needed.

Conventional versus Statistical Safety

Conventional safety and statistical safety (Figure 2) were considered thoroughly during the program definition phase before making the decision to structure the Instrument Safety Guide on the conventional safety basis.

INSTRUMENT SAFETY PRACTICE

CONVENTIONAL SAFETY

- rISG DEFINES REQUIREMENTS.
- ENGINEER DETERMINES AREA CLASSIFICATION.
- ENGINEER SPECIFIES OR BUYS APPROVED INSTRUMENT.

STATISTICAL SAFETY

- SAFETY HANDBOOK PROVIDES DETERMINISTIC AND STATISTICAL SAFETY DATA.
- ENGINEER ESTABLISHES DEGREE OF SAFETY SPEC.
- INSTRUMENT PROCURED TO MEET DEGREE OF SAFETY SPECS.

Figure 2

Conventional safety (or absolute safety) is safety as practiced today. An instrument is either safe or unsafe according to this concept. Degree of safety is not expressed in quantitative terms in conventional safety. The legalistic view is that things are safe or unsafe. The safety engineer would use the Instrument Safety Guide to determine area safety classification. Then he would specify or buy the instrument accordingly. The onus of realizing a safe instrument, given the location classification, would be on the instrument and/or underwriter laboratories.

Statistical safety is a term which connot[illegible] the true nature of safety. Degree of safety can be quantified statistically in terms such as probability of a hazardous event, probability of damage, probability of injury, failure rate, etc. The safety engineer would establish an instrument safety spec from deterministic and statistical data in a safety handbook. The instrument would be procurred to meet degree-of-safety specs. The burden of providing the instrument having a specified degree of safety would rest with the manufacturer.

In both approaches, the safety engineer at the munitions plant establishes the safety requirements in accordance with an accepted safety document. The instrument manufacturer then has the problem of meeting the requirements in accordance with the same safety document. This division of responsibility is necessary for establishing and meeting safety requirements.

Safety Guide Scope

The contents of the rISG, which is structured much like "Recommended Practice, Intrinsically Safe and Non-Incendive Electrical Instruments," Instrument Society of America - RP12.2, is summarized in Figure 3.

CONTENTS OF RECOMMENDED INSTRUMENT SAFETY GUIDE

1. PURPOSE
2. SCOPE
3. DEFINITIONS
4. IGNITION DATA
5. INTRINSICALLY SAFE INSTRUMENTS
6. NON-INCENDIVE INSTRUMENTS
7. OTHER TYPES OF SAFE INSTRUMENTS
8. LOCATION CLASS DETERMINATION
9. SAFETY COMPLIANCE CRITERIA
10. HUMAN SAFETY

APPENDICES

Figure 3

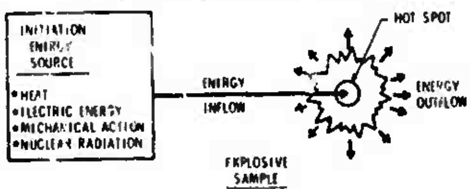
The scope of the rISG, however, is broader since it covers more types of safe instruments, location classification, and quantitative safety compliance criteria. The features of the rISG are discussed later.

Explosives Initiation

Explosives experts agree that explosive initiation is a thermo-chemical reaction which is described mathematically by the hot spot theory (Figure 4). According to this theory, an initiation energy source injects energy into a sample of explosive rapidly enough to cause the hot spot which causes ignition and/or explosion. This occurs in accordance with the Frank-

Kamenetski equation shown in the figure. Most organic explosives are good thermal insulators so that a hot spot can occur with relatively small energy inflow. The hot spot is caused by heat input or by other forms of energy which are partially absorbed by loss mechanisms in the explosives, resulting in the hot spot. The energy not absorbed from these energy sources escapes the system. Electric spark energy is a good example of this phenomenon, and estimates are that 90 to 95 percent of the spark energy leaves the system as light, sound, electrode heating, etc.

HOT SPOT THEORY OF EXPLOSIONS



FORMATION OF HOT SPOT IS GOVERNED BY FRANK-KAMENETSKI EQUATION

$$c\rho \frac{dT}{dt} = k\nabla^2 T + \rho Q K_r e^{-1/RT} + \dot{Q}$$

THERMAL CAPACITANCE — HEAT CONDUCTION — ARRHENIUS DECOMPOSITION — HEAT INJECTED

Figure 4

Explosives initiation experts agree further that there are four levels of explosives thermal decomposition – initiation, deflagration, transition and detonation. Figure 5 shows these levels as graphs of energy flux input and hot-spot temperature versus time. The energy flux input is removed after a certain time interval as shown.

BASIC TYPES OF DECOMPOSITION

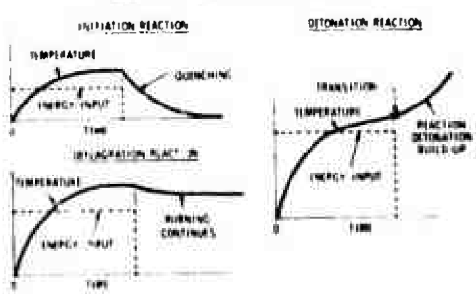


Figure 5

The lowest level of decomposition is initiation which requires a sustaining energy source. This is analogous to the charring of a piece of wood by a match, which quenches when the match is removed. Initiation alone is not hazardous, although it is frequently interpreted in safety circles as being a hazardous reaction level.

Deflagration is the next higher level of thermal decomposition. It does not require a sustaining energy source, and the heat produced by Arrhenius decomposition is sufficient to propagate the reaction. Deflagration is similar to ordinary burning. It starts with initiation which builds to deflagration status.

Transition is the level in a deflagration at which the reaction reaches the level of instability.

The Arrhenius decomposition at the next higher level, which is detonation, produces heat faster than it is carried away by thermal conduction. The thermal reaction then propagates at sonic velocity in the explosive, and the reaction occurs nearly instantly.

From the standpoint of explosives safety, the levels of decomposition of concern are deflagration, transition, and detonation. Ignition per se is not hazardous if it does not grow to the deflagration level. Data from spark ignition tests, however, shows that the energy required to cause deflagration may be orders of magnitude above that required for initiation. On the other hand, past safety practice, in general, interprets initiation as the hazardous event. Most investigators generally have not distinguished adequately between an initiation event and deflagration or explosion. The net result in safety practice is excessive conservatism.

Initiation Energy Sources

Initiation-energy sources include direct heat sources, indirect heat sources and (in theory, at least) tribo-chemical sources.

Direct heat sources are conduction, thermal radiation, and convection.

Indirect heat sources are electric current and electromagnetic radiation which can cause heating by mechanical, electrical and electromechanical mechanisms. Mechanical

action causes heating by inelastic deformation of the explosive and by adiabatic heating. Nuclear radiation energy is partially absorbed causing heating. The energy of indirect heat sources in most instances is only partially absorbed in the explosive. This explains why very large electric spark energy is required to produce explosion.

Tribo-chemical sources of initiation have been postulated but not proven to exist. The energy of a tribo-chemical source would cause initiation or explosion without the intermediate process of conversion to heat.

Framework for Hazardous Locations

The rISG instrument safety guide framework for hazardous locations is shown in Figure 6. It has been defined to mesh with that of existing safety codes and standards.

INSTRUMENT SAFETY GUIDE FRAMEWORK FOR HAZARDOUS LOCATIONS

LOCATION CLASSES

• PRESENT NEC	• ADDITIONAL FOR rISG
I GASES AND VAPORS	IV PARTICLES, PELLETS, FLAKES, CHUNKS, TURNINGS
II DUSTS	V LIQUIDS AND SLURRIES
III FIBERS AND FLYINGS	VI PRESSINGS

DIVISIONS

• PRESENT NEC	• ADDITIONAL FOR rISG
1 FREQUENTLY OR ALWAYS HAZARDOUS	NONE
2 HAZARDOUS ONLY FOR ABNORMAL CONDITIONS	

GROUPS

• PRESENT NEC	• ADDITIONAL FOR rISG
A ACETYLENE	NO RECOMMENDATIONS
B HYDROGEN OR EQUIVALENT	
C ETHYLENE OR EQUIVALENT	
D PENTANE OR EQUIVALENT	
E METAL DUST	
F CARBON BLACK OR EQUIVALENT	
G GRAIN DUST OR EQUIVALENT	

Figure 6

The present framework of the NEC consists of location classes, divisions, and groups as shown on the left side of the figure.

The additional location classes recommended in the rISG are physical states in which explosives are processed and are considered hazardous. Class IV is various solid forms of explosives which are processed and which are larger than dust particles. Dust particles, Class II, are particles smaller than 840 microns. That is, they will pass through an 840-micron screen (USS Sieve No. 20). Class IIa, Dust Layers, and Class IIb, Dust Clouds, also are separate categories of dust in the rISG. Pressings, Class VI, is a somewhat porous solid state obtained by pressing dust or small particles.

Class V, Liquids and Slurries, is the melted state in which explosives are poured into munition items such as artillery shells and bombs. This is the second most sensitive state.

Class I, Gases and Vapors, is not a very hazardous state of most explosives since the vapor pressure generally is very low at the maximum processing temperature. Generally explosives are heated to only 5 or 10°F above melting temperature for pouring operations, which partially explains why the vapor pressure is low. The military chooses low-volatility explosives if possible.

Class III, Fibers and Flyings, is retained principally because it is part of the present NEC framework and is of value mostly for textiles. It appears to have minimal importance for explosives.

Divisions needed for the rISG are the same as for the present NEC. Division 1 locations are frequently or always hazardous whereas Division 2 locations are hazardous only under abnormal conditions.

Seven different chemical groups are defined in the present NEC. Four groups are hazardous gases and three groups are hazardous dusts. Explosives would constitute one or more additional groups. Recommendation for explosive groups were not made because it was felt that the amount of initiation data available does not justify groups at present. Groups likely should be defined at a future time on an energy basis covering the various basic categories of initiation energy.

Initiation Data Base

The rISG initiation data base is shown in Figure 7 for each of the safety guide hazard (location) classes. The left-hand column identifies the data source. For example the first entry, Class IIa, Spark Ignition Data -- Dust Layers, identifies the basic

type of test from which data was obtained. This data applies to Class IIa, Dust Layers, as indicated by the word "Test." It also is assumed to apply safely to Classes III, IV, V, and VI, since these classes represent less sensitive physical states of the material. In other words, in the absence of test data for these other classes of material, electrical ignition data for dust layers may be used conservatively as energy levels at which these materials will not ignite.

INITIATION DATA BASE

ORIGINAL TEST OR COMPUTED DATA	SAFETY GUIDE HAZARD CLASSES						
	GASES & VAPORS	IIa DUST LAYERS	IIb DUST CLOUDS	III FIBERS & FLYINGS	IV PARTICLES PELLETS FLAKES CHUNKS TURNINGS	V LIQUIDS AND SLURRIES	VI PRESSINGS
CLASS IIa SPARK IGNITION DATA DUST LAYERS		TEST		X	X	X	X
CLASS IIb SPARK IGNITION DATA DUST CLOUDS			TEST				
CLASS I COMPUTED FROM VAPOR PRESSURE DATA	COMP'D						
CLASS IIa NUCLEAR RADIATION DATA	X	TEST	X	X	X	X	X
CLASS IIa STATIC SAFETY DATA		TEST		X	X		
CLASS IIa PRESSING PRACTICE DATA		TEST		X	X		
CLASS IIa AND V EXPLOSION TEMP DATA		TEST		X	X	TEST	X

Figure 7

Figure 7 identifies the test data on which the code is based by the word "Test" in appropriate columns and Xs where the test is also assumed to apply. It may be seen that most test data available is for dust layers. This includes electric spark data and nuclear radiation data (from Los Alamos Scientific Laboratories), static stress data (from Bridgeman), pressing practice data (from Army publications), and explosion temperature data (from Army publications). Explosion temperature data applies also to liquids and slurries since many of the explosives melt below the explosion temperature. Dust is the most sensitive form of explosives and dust data may be used if other data is not available. Therefore Class IIa data (Dust Layers) is used as necessary for Classes III, IV, V, and VI, which are classes for which data is practically nonexistent.

Data for gases and vapors was computed from vapor pressure data and theoretical heat of combustion. The heat, Q_a, required to increase a unit volume of air from the temperature of the vapor to the explosion decomposition temperature of the explosion was calculated, assuming the constant volume specific heat for air. Then the amount of heat, Q_e, from the combustion of the vapor at the vapor concentration was calculated. These two heat values were compared. For deflagration to occur, it is necessary that $Q_e > Q_a$. Safe vapor temperature was then computed, and it is a temperature of melted material which is below that needed to produce a deflagrable concentration of vapor.

Instrument Safety Classifications

The instrument safety classifications covered by the instrument safety guide are listed in Figure 8.

SAFETY CLASSIFICATIONS OF INSTRUMENTS

- INTRINSICALLY SAFE INSTRUMENT
- NON-INCENDIVE INSTRUMENT
- DUST-IGNITION-PROOF INSTRUMENT
- EXPLOSION-PROOF INSTRUMENT
- PURGED INSTRUMENT
- IGNITION CAPABLE INSTRUMENT
- PRESSURIZED-ENCLOSURE INSTRUMENT

Figure 8

An intrinsically safe instrument is incapable of releasing sufficient energy under normal or abnormal conditions to cause deflagration. Normal conditions include maximum supply voltage and extreme environmental conditions; shorting, opening or grounding of connecting wiring in intrinsically safe portion of the instrument; and normal conditions required for other primary or special ratings. Abnormal conditions include any two faults in combination, except that, if one fault is highly improbable, the instrument is intrinsically safe if neither fault can cause a specified hazardous energy level.

A non-incendive instrument is similar to the intrinsically safe instrument except that it may contain energy sources potentially capable of causing deflagration if they are satisfactorily protected. It may be installed in Division 2 areas in general-purpose enclosures.

A dust-ignition-proof instrument is one which (1) is enclosed to exclude deflagrable amounts of dust, and (2) will not cause deflagration of an exterior accumulation of dust.

An explosion-proof instrument is one enclosed in a case which will (1) withstand an explosive decomposition event within it and (2) prevent the propagation of such an event to a material located externally.

A purged instrument is one in which purging is used to prevent a deflagrable accumulation of explosive or other combustible gas.

An ignition-capable instrument is one which, in its normal operating conditions, can cause a decomposition event. It may be used within a suitable enclosure (NEMA Type 12 for Division 1 or NEMA Type 1 for Division 2).

A pressurized-enclosure instrument is one located in an enclosure with sufficient internal pressure to exclude deflagrable amounts of explosive.

Intrinsic safety is considered the most desirable approach to safety, since energy levels do not exist under possible fault conditions which could cause an explosive decomposition event.

Intrinsic Safety

Intrinsically safe instrument classes and ratings in the rISG (Figure 9) depart significantly from present-day instrument safety classes. Present-day intrinsic safety practice encompasses only electrical instruments in which electrical spark energy is of principal concern.

INTRINSICALLY SAFE INSTRUMENT CLASSES AND RATINGS

INSTRUMENT CLASS	ELECTRICAL	THERMAL	MECHANICAL ACTION	RADIATION
ELECTRICAL	P	P	S	S
MECHANICAL	S	P	P	S
RADIATION	P	P	S	P

P - PRIMARY RATING

S - SPECIAL RATING

Figure 9

However, explosives may be initiated by any source which can inject hazardous energy. This is borne out in present munitions plant safety practices by the painstaking attention to mechanical, thermal, and nuclear radiation equipment in addition to that given to electrical equipment. The rISG recognizes this by defining the three classes of intrinsically safe instruments shown in the figure -- electrical, mechanical, and radiational. One also could specify a thermal class, but it would have few if any applications in instrumentation. Many mechanical instruments are used, which is a class intended to include pneumatic and hydraulic instruments. Radiational instruments are intended to cover both nuclear and electromagnetic radiation over the entire spectrum.

The terms primary rating and secondary rating were coined to account for the various kinds of hazardous energy associated with a given class of instrument. For example most electrical instruments generate heat so that both electric discharges and hot spots are of concern from a safety standpoint. The primary electrical and thermal ratings for the electrical instrument means that any electrical instrument must not generate hot-spot temperatures greater than a specified maximum and that it is mandatory in establishing an intrinsically safe rating for an electrical instrument that it comply with thermal requirements.

An electrical instrument also may have moving mechanical parts or it might function using electromagnetic radiation. The secondary rating is intended to account for these possibilities if they exist. The secondary rating must be considered if the instrument could generate the type of hazardous energy indicated.

The three classes of intrinsically safe instruments, therefore, have primary and secondary ratings as indicated. The process of rating (that is, assuring safety) for other types of energy sources is not new. Only the formalization of the process is new. This recommended method of considering all potentially hazardous energy sources in rating an instrument will assure uniformity of practice and essentially guarantee that all potential hazards are covered.

Location Classes

The general location classification scheme (Figure 10) is basic to all six location classes. It is intended that location classification be practiced only by experienced safety engineers.

GENERAL LOCATION CLASSIFICATION SCHEME

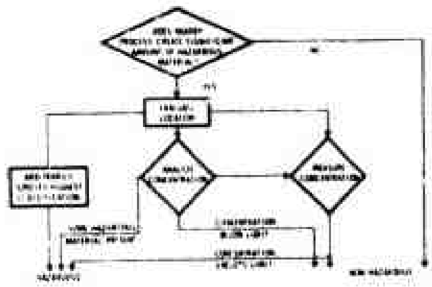


Figure 10

First, an instrument location may be hazardous because a nearby process produces hazardous quantities of explosives. An experienced safety engineer can determine if there is a significant probability that a proposed instrument location is in a hazardous location. He classifies the area as non-hazardous if he determines that the nearby process does not produce a hazardous concentration of explosive material. He evaluates the location however if he determines there is a significant probability that a hazardous concentration might exist.

There are three alternatives in evaluating the location.

First he can arbitrarily classify it as a hazardous location if he knows it is hazardous or if he desires to avoid the problem of analyzing or measuring the concentration when these procedures are not feasible. The disadvantage of this procedure is possible overclassification and the attendant economic penalties.

Second, he may analyze the concentration if this procedure is feasible. Analysis methods are defined in the rISG. The area is classified as hazardous or non-hazardous in accordance with analytical results.

Third, he may measure the concentration by methods defined in the rISG. Measurement is the best single classification approach because it tends to provide the highest confidence in the data. The area is classified hazardous or non-hazardous in accordance with the measurements and allowable concentration data in the rISG.

Also there is a fourth alternative in location classification which consists of both analysis and measurement of the concentration. This is the best approach available and provides maximum confidence in the results.

Safety Compliance Criteria

The rISG sets forth the safety compliance criteria shown in Figure 11. This criteria is quoted as follows: "Single or combined parts failure rates (faults) in instruments, which might cause hazardous energy discharges at the rate of 10^{-10}/hr or less shall be construed to be absolutely safe. Single or combined parts failure rates which might cause hazardous energy discharge greater than 10^{-10}/hr shall be construed as unsafe." This safety compliance criteria may be stated by the mathematical inequality shown in the figure.

SAFETY COMPLIANCE CRITERIA

$$P\,(H_{f_1} + H_{f_2} + \cdots + H_{f_n}) \leq 10^{-10}/\text{HR}$$

H_{f_n} = nth POTENTIALLY HAZARDOUS FAULT

BASIS

$$\begin{pmatrix} \text{3 SHIFTS/DAY} \\ \text{100 EMPLOYEES/SHIFT} \\ \text{7 DAYS/WEEK} \\ \text{100 YEARS OPERATION} \\ \text{100 INSTRUMENTS/PLANT} \end{pmatrix} = 0.876 \times 10^{10} \text{ HRS OF EXPOSURE TO HAZARD}$$

VALUES

SUBJECTIVE JUDGMENT ELIMINATED
RELATES SAFETY TO RELIABILITY

Figure 11

This means that the probability of a potentially hazardous event (instrument failure) is no greater than one event per 10^{10} hours of operation. The "basis" of this is shown on the figure. The total human exposure to hazards created by instruments in a 100 year continuous plant operation at 7 days/week, 3 shifts per day, 100 employees/shift, with 100 such instruments amounts to

less than 10^{10} hours of total exposure to instrument hazards on a per-instrument basis.

This safety compliance criteria should reduce subjective judgment, and it will provide a basis for relating safety to conventional reliability.

There has not been a basis in any recognized safety practice of making use of present-day reliability information in quantizing safety, even though it is known that safety has a statistical nature. A basic requirement for intrinsically safe instruments and non-incendive instruments is that hazardous energy not be discharged for any two possible faults which might occur. Faults which are considered to be sufficiently improbable are regarded as being impossible. The fallacy of this is apparent.

As an example of the meaning of the safety compliance criteria, an instrument may have a single part having a failure rate of 10^{-10}/hr which could release hazardous energy.

Similarly two parts having a combined failure rate of 10^{-10}/hr, with individual rates of 10^{-4}/hr and 10^{-6}/hr, which could release hazardous energy in combination would be acceptable. Larger failure rates however would not be acceptable.

The 10^{-10}/hr single or combined parts failure rate figure is considered to be a good choice for the following reasons:

The overall safety factor for instrument safety purposes is substantially greater than the 10^{-10}/hr figure implied for the following two reasons:

(1) The probability of ignition or explosion given the hazardous event has not been included, even though generally speaking it will be a small probability.

(2) Specified allowable ignition levels have a large built-in factor of safety.

The hazardous fault per 10^{8} hours of operation of 100 instruments is equivalent to 50,000 man years at a normal workweek rate. The 10^{-10} figure establishes essentially absolute safety.

The 10^{-10}/hr failure rate is not excessively restrictive from the design point of view for combined failures. It would not lead to excessive instrument costs.

<u>Summary</u>

This paper has briefly outlined the more important aspects of the rISG. In summary: The rISG provides broad safety coverage for munitions plant instruments. It covers the various methods of instrument safety realization, and it includes mechanical instruments and radiational instruments as well as electrical instruments in the safety framework. New location classes, viz. IV, V, and VI, are included in the framework for munition plants. The rISG is the most recent safety document available for munition plant instrument safety.

The rISG has not been approved or adopted by any safety governing body. It is not known if it will be adopted, or modified in the future.

Likely, it will be studied and used to a limited extent by the U.S. Army and perhaps others. There is the possibility of future modification and/or adoption by the Army, other DOD organizations, and national safety governing bodies such as the National Fire Protection Association.

DETONATION TRAPS TO PREVENT PROPAGATION OF EXPLOSION IN PIPE LINES CONVEYING EXPLOSIVE FLUIDS

By

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As part of the Army's Plant Modernization Program, a new continuous process for melting explosives (TNT, Comp B, etc) is being developed at Picatinny Arsenal. For the first time, molten explosive will be pumped from the process area to the loading station. In order to safeguard against propagation of an accidental detonation through the pipeline, a novel detonation trap (DT) is being developed which can sense an explosion and arrest it within one millisecond.

Prior to this, there was no satisfactory method for stopping a detonation from propagating throughout an explosive loading system containing molten TNT or Composition B. Techniques were devised in the past which were based on critical diameter, loops, etc. However, these were not practical in plant operations where large volumes of molten explosive were being processed, because the small critical diameter would restrict the flow excessively and the loops would hamper it. Existing plants which manufacture or process explosives have no safety devices to thwart an accidental explosion. In an incident (1968) at Louisiana Army Ammunition Plant, serious property-damage and loss of life resulted from an accidental detonation which propagated through the entire system.

In the current state-of-the-art, melting and loading operations for

for artillery shell are conducted in the same industrial building. There are no safety devices (other than expensive barricades) to protect life and property against accidental detonation. If the melting operation could be accomplished in one building and the loading operation in another (safety removed) a major improvement in safety could be obtained. Furthermore, if the buildings could be joined by process piping (which carries molten explosive from the melt point to the load point) and if detonation traps could be installed in the pipeline, an accidental detonation in one part of the system could be arrested before propagating to the other. Personnel, buildings and equipment could thus be effectively protected at a relatively low cost.

Recognizing the limitations of existing methods for melting and loading ammunition, a completely new continuous, automated melt-pour process was devised to accomplish this more safely and efficiently in accordance with the above. However, it was evident that the detonation trap was the key element in this process and that development of the overall process really hinged on the successfuldevelopment of this component. A program was initiated which led to the development of the PDT-1 device. During the course of this project, reviews were held with AMC Safety Office and the Dept of Defense Explosives Safety Board. Both organizations approved of the design and concurred in the technical approach. The following is a brief description of the DT device and results of the feasibility test demonstration.

Figure 1 shows an elementary schematic of the detonation trap concept. It consists of three basic components: the sensor, the power supply and the valve or trap portion. When a detonation occurs upstream, the pipe fragments and the wire breaks. This activates the power supply, which in turn actuates the valve. A plug is injected radially which intercepts the

detonation wave, attenuates it to a low energy level and literally traps it in the line. The wave is thereby prevented from further propagation downstream past the valve. The concept emphasizes redundancy to a large degree. Dual sensors, power sources, actuators and DT valves are employed for reliability. The detonation trap system consists of two DT units in tandem with a duality of associated components.

Figure 2 shows a cross section of the trap in both the open and the closed positions. In the open position, a hole in the plug is aligned with the opening in the pipe. The plug itself consists of a hollow maraging steel cylinder with a teflon envelope. The hollow portion is filled with a low density foam or hollow glass beads to preserve the air quality of the design without incurring the effects of spalling. Air is an excellent attenuator. As such, a hollow plug is a more effective device than a solid plug. The teflon provides friction free movement in the channel and closure is accomplished by a tapered hole in the base which restricts the motion of the soft aluminum extremity of the plug. Movement of the plug is accomplished by redundant M36A1 detonators. When the plug moves downward, it shears the molten explosive and carries down the portion contained in the plug. Hence, there is no impact, squeezing or friction imposed on the explosive during trap operation.

Figure 3 shows an in-line view of all the hardware components of the trap. From left to right, the following can be seen: the trap housing, the aluminum extremity of the plug, the teflon envelope, the hollow steel plug, hollow glass beads, the plug closure, an asbestos-phenolic cup for the RDX booster charge, an asbestos-phenolic container for the detonators, a teflon washer, an insert cap and a closure cap.

Figure 4 shows a schematic of the test set-up and Figure 5 shows a photo

of the full scale test set-up used in the feasibility demonstration of the detonation trap principle. A 30-foot steam jacketed pipe, with insulation, containing molten Comp B was assembled as shown with the detonation trap at the extreme right end. A steam feeder line main is shown at the right extending from the block-house. Branch lines can also be seen feeding off the main steam line. A blasting cap and booster system (extreme left) were used to initiate the explosive pipeline. Thermocouples were installed at critical locations to monitor temperature of the explosive.

Figure 6 shows a close-up of the trap. Dual units were used in series for reliability and effectiveness. A portion of the downstream pipe is shown on the right. The mission of the trap is to protect this downstream portion from detonating. A small deflector plate was interposed between the detonation trap and the downstream pipe to prevent random impact of fragments.

Figure 7 shows the scene after detonation. The upstream pipe was completely fragmented by the high order detonation. The downstream section was preserved intact, as can be noted at the right. A closeup of this portion is shown in Figure 8. To date, three similar full scale field tests were successfully performed with response time less than one millisecond for each. It may be concluded from these that the detonation trap concept is feasible and the development represents a major step forward in safety technology.

DETONATION TRAP CONCEPT

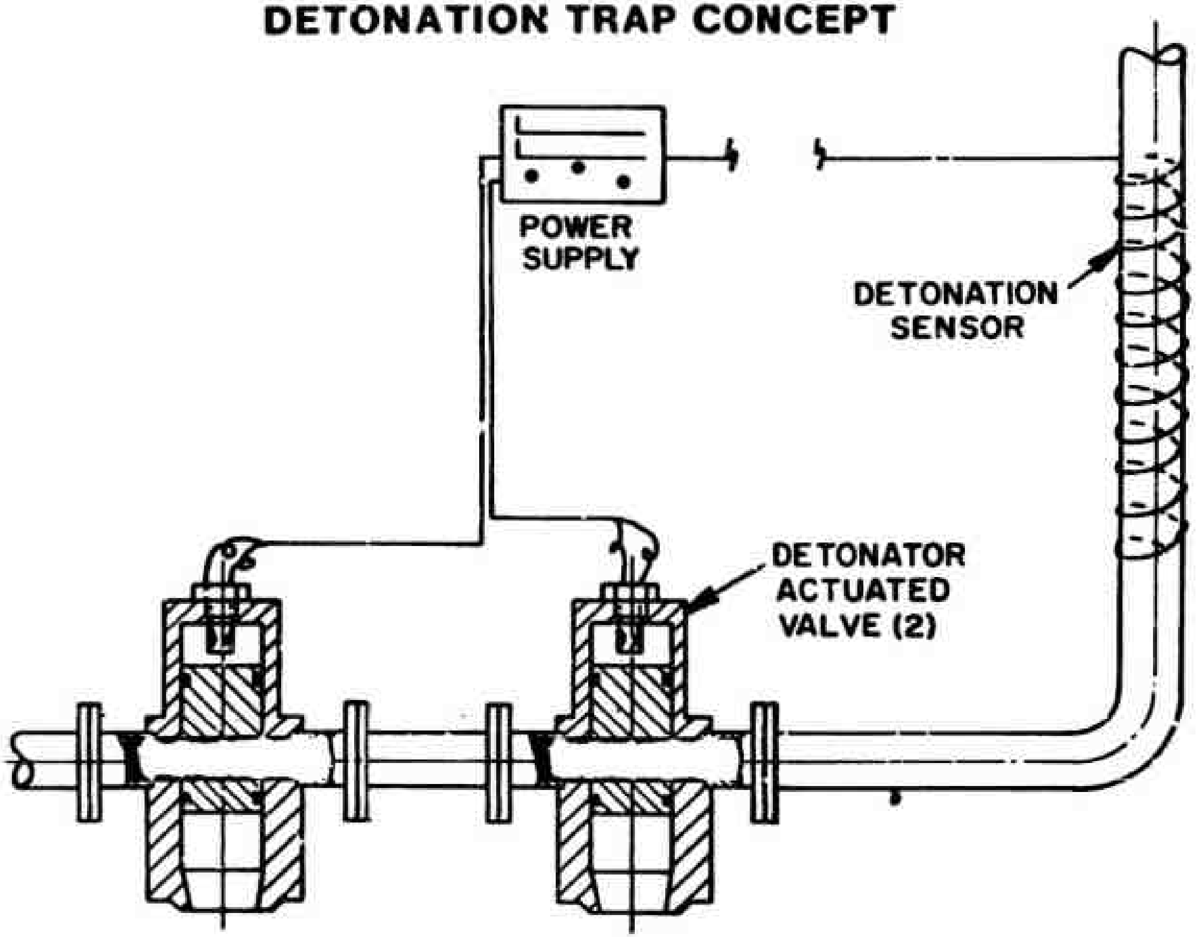
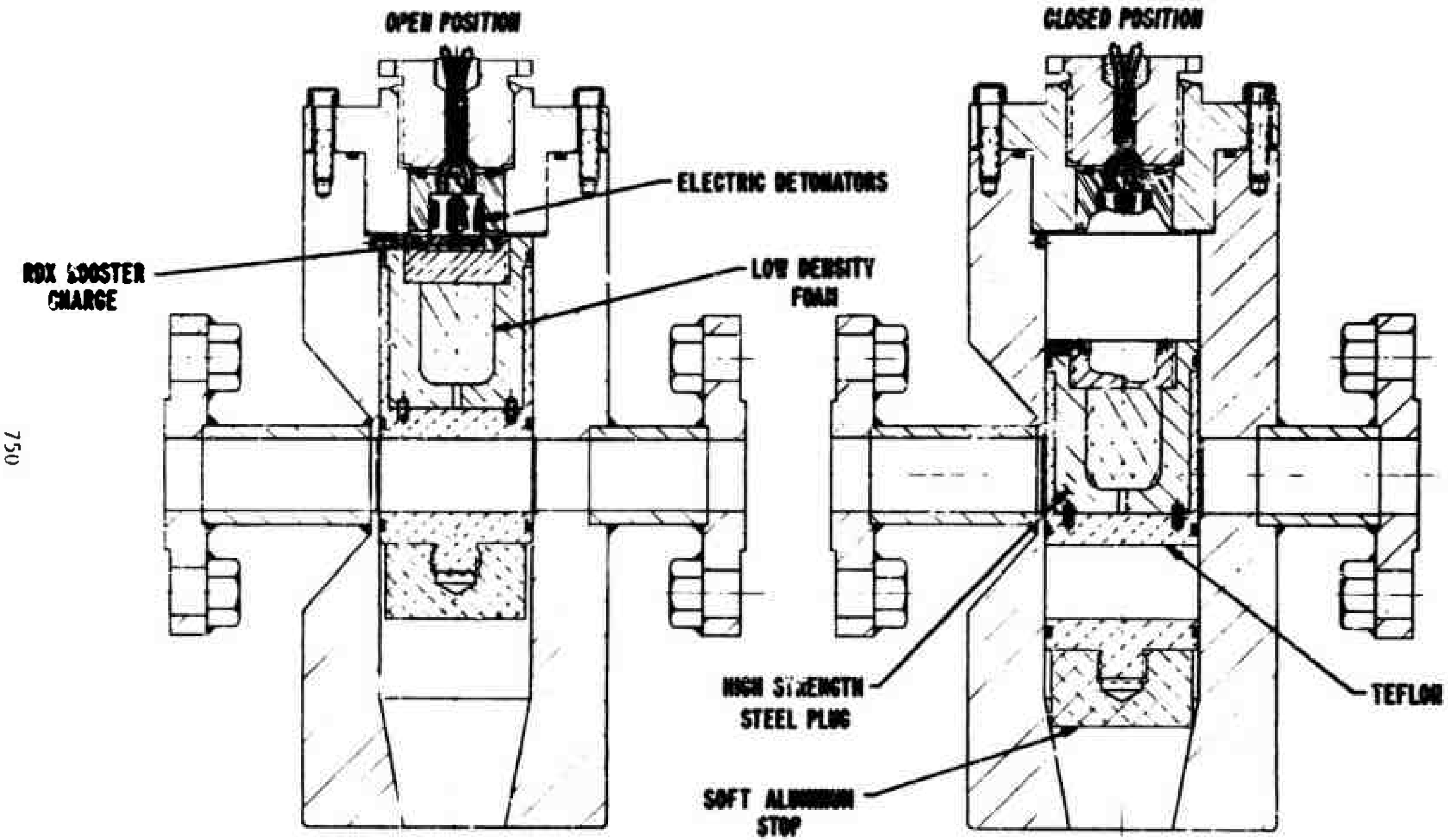
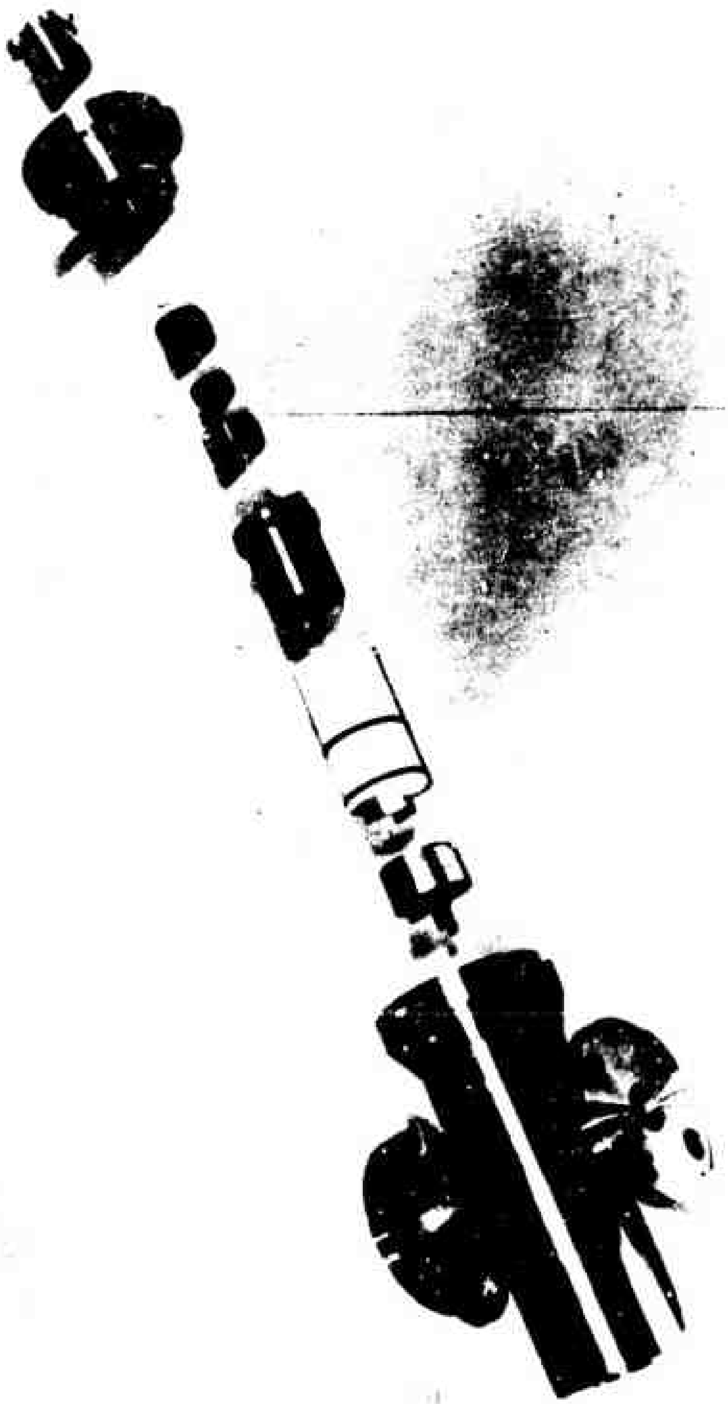
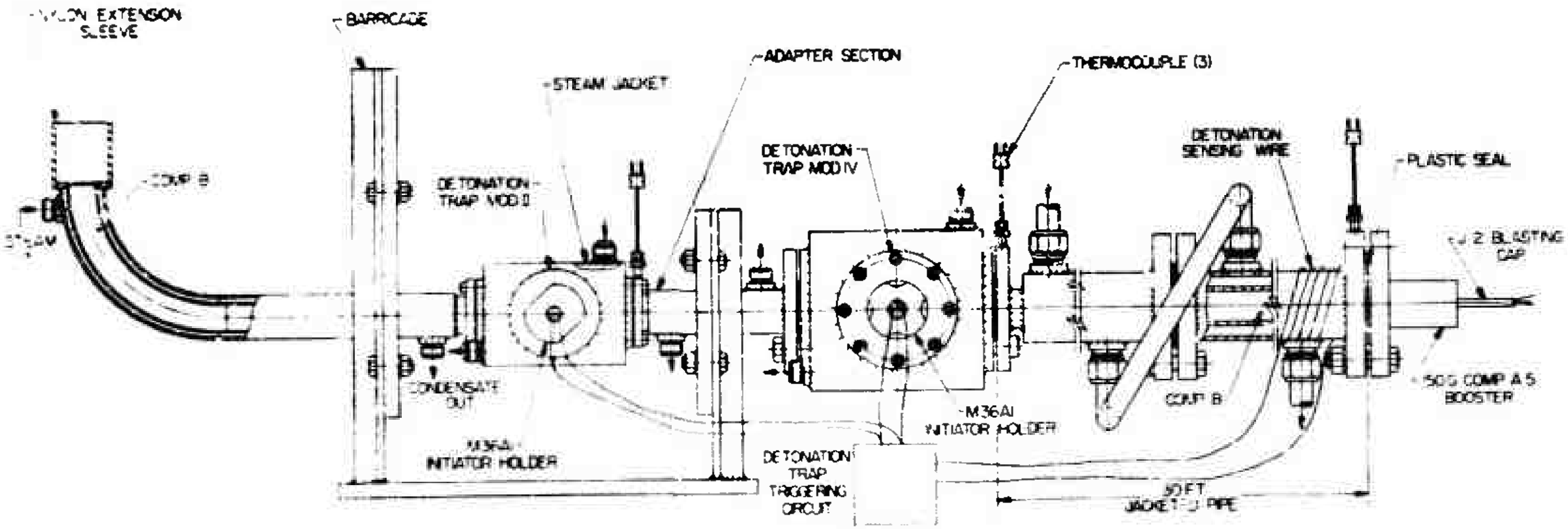


FIGURE 1

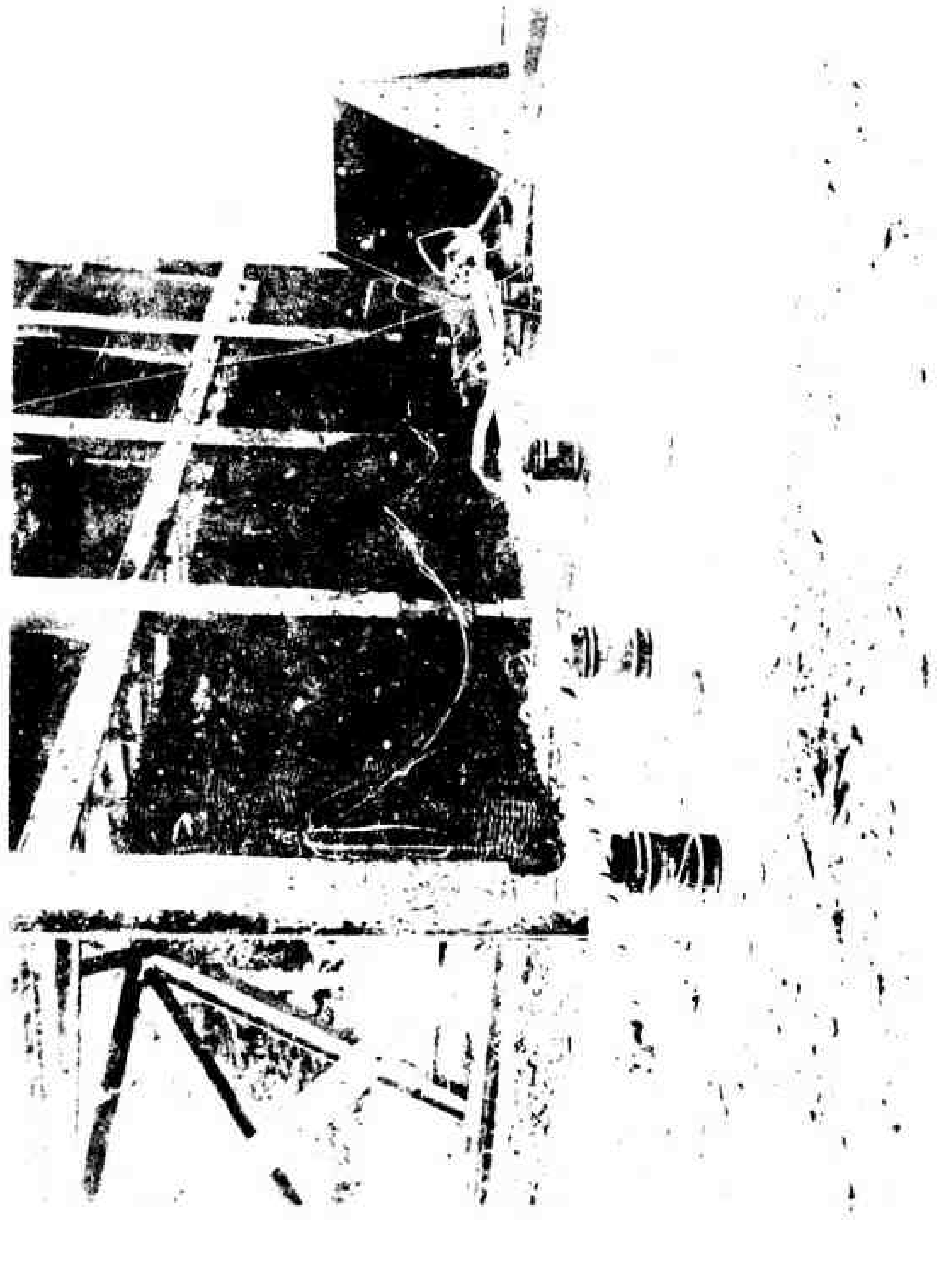


PLUG TYPE DETONATION TRAP
FIGURE 2





DETONATION TRAP TEST SET UP
FIGURE 4



STORAGE AND HANDLING PRECAUTIONS IN THE CONDUCTION OF R&D ACTIVITIES INVOLVING HYPERGOLIC PYROTECHNIC COMPOSITIONS

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In any investigation involving the use of new or untested explosive materials, storage and handling procedures must be worked out prior to actual use. In this preliminary study, trimethyl aluminum (TMA) and triethyl aluminum (TEA) were used in conjunction with other ingredients as possible pyrotechnic compositions for employment in small caliber ammunition. These hypergolic compounds are attractive because they spontaneously ignite in the presence of oxygen, thereby igniting the pyrotechnic composition as well as enhancing its burning characteristics. This same property of spontaneous ignition prompted us to conduct a hazards analysis on triethyl aluminum, the ingredient used predominantly throughout this investigation.

Before going into the hazards analysis, however, let's take a look at the properties of TEA (Figure 1). Because it has a boiling point of 194°C, there is little hazard from vaporization. However, it does react spontaneously with air, and quite violently with water. This latter characteristic is of interest, since the human body itself is composed of approximately seventy percent water. The explosive hazard is due to the fact that a decomposition product is ethane, which is detonatable with air.

Hazards Analysis: The pyrotechnic compositions of interest contain various inorganic oxidizers and finely powdered metals. Because of its energetic and unstable nature, it was necessary to determine the compatability of TEA with these ingredients. Since the TEA/oxidizer is the most likely to be the least stable combination, the compatabilities

of TEA with various inorganic oxidizers were determined first. This was accomplished by adding two milliliters of TEA to 2 to 3 grams of each oxidizer (shown in Figure 2), and observing the combination for signs of smoking or fuming (which are indicative of reaction). The mixtures were all placed in a glove box under a positive nitrogen atmosphere.

As you can see from the figure, there were two categories of combinations determined from this experiment -- compatible and incompatible. It is also apparent that all the nitrate salts tested were compatible, while only some of the perchlorate and chlorates were. Furthermore, the sodium salts used were all compatible. Now, it should be noted that this compatability experiment was short term only, involving a three-day monitoring period; the long term stability of TEA/oxidizer combinations has not been determined.

There are criteria other than compatability for the use of TEA mixtures in small caliber ammunition, as shown in Figure 3. These include not only compatability of the ingredients with each other and with their environment, but also acceptable burning rates, ignition delays and light outputs.

Those combinations of ingredients having short-term compatability were further examined as to their behavior in the presence of air, which as we know, is made up of approximately 21 percent oxygen. This was accomplished by pouring the compatible mixtures into small glass vials and sealing them in a nitrogen atmosphere, and then removing them from the glove box onto a lab bench, where the vials are then broken. Three characteristics were of interest to us in this experiment: ignition delay time (that is, the time elapsed from air exposure

to an observable reaction); the burning rate of the reacting combination; and the intensity or "brightness" of the observed flame. Figure 4 gives reeulte of our qualitetive evaluation of six of the better candidate combinetione of TEA and an oxidizer. The terms used in this Figure (slow, fast; short, long; high, low) are only qualitative and are used only in a comperative context. However, the two sodium compounds -- sodium chlorate and sodium peroxide-do produce higher light output than all the others. Therefore these two oxidizere were ueed in all subsequent work.

The next step was that of evaluating the characteristice of complete mixtures, which include TEA/oxidizar/matal or metal hydride. This was accomplished using a similar procedura to that previously described. The results (eea Figure 5) indicate that euperior burning and brightnese charecteristics could be echieved with compoeitione containing sodium chlorate and magnesium, or sodium chlorate and boron with TEA. Note that the terms ueed here are again comparetive (the "B" under the "brightness" column indicates e very brillient output) -- but in this case the control mixture egainst which they are compared is the Army's standard tracar formulation, R 284.

Incidently, polyisobutylena (PIB) has been found to be an acceptable thickening agent for theee liquid-like compositions. I will not go into detail on this part of the invastigation, other than to say thet PIB renders the compositions less pyrophoric.

One finding of our investigation coming into play at this stage was that the ignition delay time was greatly reduced by using a 50/50 mole percent mixture of TEA/TMA. From the standpoint of safety, this means that the TEA/TMA mixture is more reactive with air than the separate ingredients. This finding was quite helpful to us, since it meant that we could direct attention to other oxidizers and metals previously ruled out because of the long ignition delays of their mixtures.

Further development of these compositions led to what we called our final formulations (Figure 6), which contain the metals magnesium or zirconium and oxidizers sodium chlorate or strontium nitrate. The five mixtures shown on this slide have short ignition delay times, fast burning rates and burn with a brilliant intensity. An example of the appearance of the flame, when a composition burns inside a steel cavity, is shown in Figure 7, which is for the zirconium/sodium chlorate composition TI-3B. Especially impressive for this composition, was the relative height of the flame obtained with only a 1/2-gram sample.

The problem of loading these mixtures into metal cavities and sealing them involved working in a nitrogen atmosphere in a glove box, as shown in Figure 8. Here the technician is using a hypodermic needle to inject the compositions into the cavities. At the first sign of fuming or smoking, all operations are brought to a halt, and the glove box atmosphere checked for oxygen content or moisture--either one of which may react with the hypergolic materials.

Figure 9 shows tools used in loading cavities with hypergolic materials. These include funnels (both glass and metal); brushes; tweezers; and hypodermic needles. The hypodermic needle approach, with its positive displacement principle, was found to be the best loading technique available, as the hypergolic material is free from oxygen or moisture while in the syringe.

The final batch of charged cavities were, in effect, tracer or spotter projectiles. The tracers were sealed with various foiling materials, the best of which were aluminum foils with silicone or acrylic adhesive coatings. For shipping purposes, the loaded tracers were placed into glass or polyethylene bottles while under a nitrogen atmosphere, the remaining space being filled with fine vermiculite. During the entire time these projectiles were being handled, because of the risk of body burns, personnel were required to wear safety glasses, heavy rubber gloves, and lab. coats. Furthermore, because of the small amounts of these materials present, vermiculite was to be used as an extinguishing agent should the need arise. It is to be noted that at no time should water be used in an attempt to extinguish an aluminum alkyl fire; water reacts rapidly and violently with the aluminum alkyls.

Now, to summarize (see Figure 10), the objectivas of thia program were to avaluata hypergolic, pyrotechnic compositions for use in tracer or spotter ammunition. This involved hazards in storing and handling these same materials. Compatability studies served to rule out undesirable candidates, as did characteristics observed during burning. Optimized systems were selected from the standpoint of having a low ignition delay, fast burning rate, and sufficiently intense flame, as well as a low ignition risk while in components. Thank you.

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FIGURE 1. PROPERTIES OF TRIETHYL ALUMINUM (TEA)

DESCRIPTION: COLORLESS LIQUID

FORMULA: $Al(C_2H_5)_3$

CONSTANTS: MW 114.15
BP 194°C
MP $<$ -18°C

FIRE HAZARD: SPONTANEOUS REACTION WITH AIR
VIOLENT REACTION WITH WATER

EXPLOSION HAZARD: MODERATE (PRESENCE OF ETHANE)

FIGURE 2. COMPATABILITY OF OXIDIZERS WITH TEA

COMPOUND	COMPATIBLE	INCOMPATIBLE
SODIUM NITRATE	X	
CHLORATE	X	
IODATE	X	
CHROMATE	X	
PEROXIDE	X	
FLUORIDE	X	
POTASSIUM NITRATE	X	
CHROMATE	X	
DICHROMATE	X	
PERMANGANATE	X	
IODATE		X
CHLORATE		X
BROMATE		X
STRONTIUM PEROXIDE	X	
NITRATE	X	
PERCHLORATE	X	
BARIUM PEROXIDE	X	
NITRATE	X	
IRON CHLORIDE		X
BISMUTH PENTOXIDE		X
AMMONIUM PERCHLORATE		X
COPPER OXIDE	X	
MANGANESE OXIDE	X	
BORON TRIOXIDE	X	

FIGURE 3. CRITERIA FOR USE OF HYPERGOLIC MATERIALS IN SMALL CALIBER AMMUNITION

A. COMPATIBILITY WITH EACH OTHER

B. COMPATIBILITY WITH ENVIRONMENT

C. ACCEPTABLE BURNING RATE

D. MINIMAL IGNITION DELAY

E. ADEQUATE LIGHT OUTPUT

FIGURE 4. BURNING CHARACTERISTICS OF TEA/OXIDIZER MIXTURES

OXIDIZER	IGNITION DELAY (SHORT, LONG)	BURNING RATE (FAST, SLOW)	BRIGHTNESS (HIGH, LOW)
SODIUM CHLORATE	S	F	H
SODIUM PEROXIDE	S	F	H
POTASSIUM DICHROMATE	S	F	L
SODIUM IODATE	S	F	L
COPPER OXIDE	S	F	L
MANGANESE OXIDE	S	F	L

FIGURE 5. BURNING CHARACTERISTICS OF TEA/OXIDIZER/METAL MIXTURES

OXIDIZER/METAL	IGNITION DELAY (SHORT, LONG)	BURNING RATE (FAST, SLOW)	BRIGHTNESS (HIGH, LOW)
SODIUM CHLORATE/MAGNESIUM	S	F	B
SODIUM CHLORATE/BORON	S	F	B
SODIUM CHLORATE/$LiAlH_4$	L	F	B
SODIUM PEROXIDE/ZrH_2	L	F	B
SODIUM PEROXIDE/ALUMINUM	L	F	B
SODIUM PEROXIDE/MAGNESIUM	L	F	B
SODIUM PEROXIDE/BORON	L	F	B

FIGURE 6. Final Hypergolic Tracer Formulations

Mixture	Composition (wt %)				
	Mg	Zr	$NaClO_3$	$Sr(NO_3)_2$	TEA/MA*
TI-3A	50		30		20
TI-3B		60	25		15
TI-3C	30	30	25		15
TI-6A	45			30	25
TI-6B	50			30	20

* 50:50 mole %

FIGURE 7. APPEARANCE OF THE FLAME FOR MIXTURE TI-3B BURNING INSIDE A STEEL CAVITY

FIGURE 9. TOOLS USED IN LOADING HYPERGOLIC MATERIALS

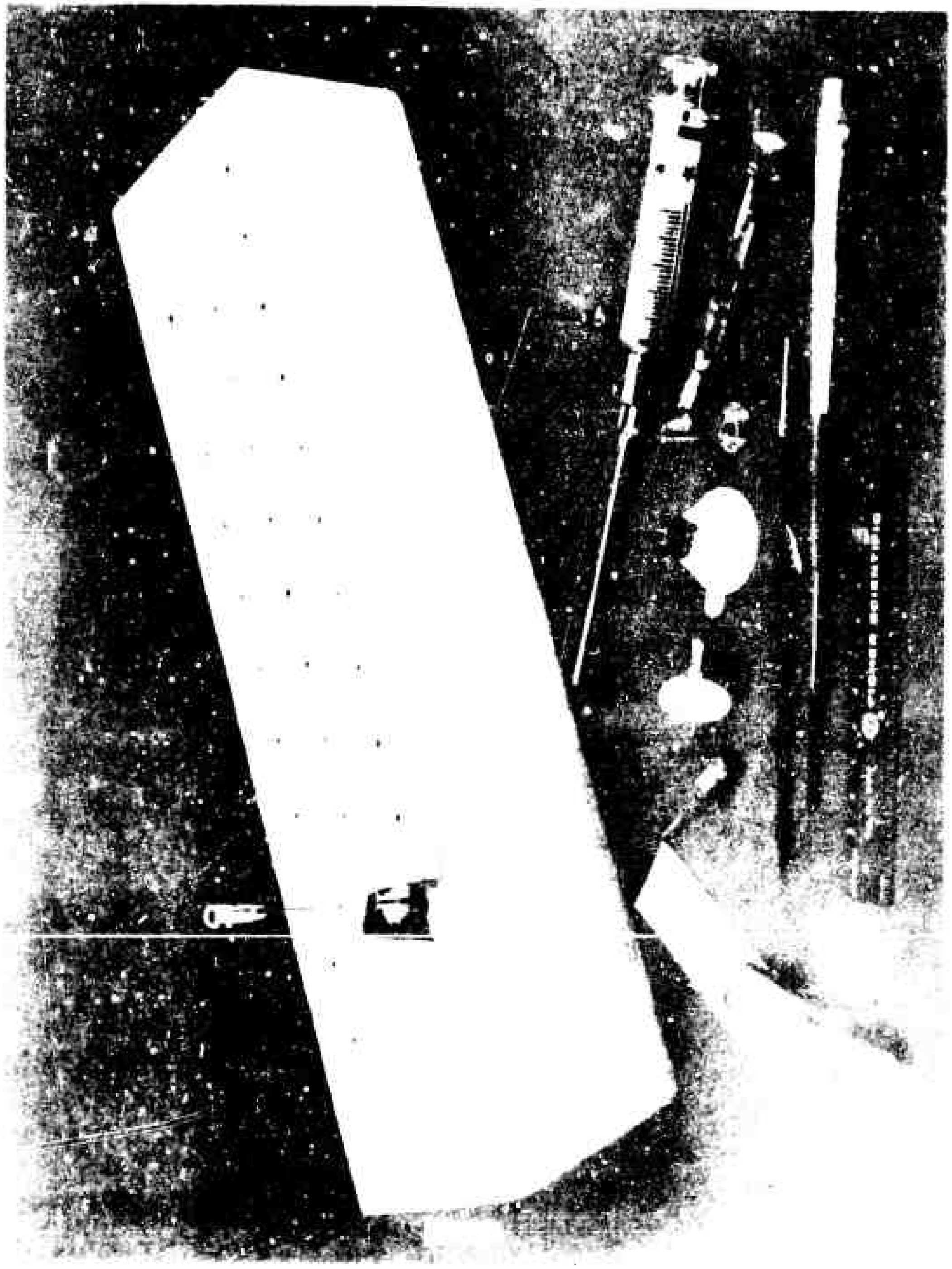

FIGURE 10. HYPERGOLIC TRACER STUDY

OBJECTIVE:

SHORT IGNITION DELAY

BRIGHT

FAST BURNING RATE

COMPATIBILITY:

TRIETHYLALUMINUM (TEA) AND OXIDIZER

BURNING CHARACTERISTICS OF TEA, OXIDIZER AND METAL

OPTIMUM SYSTEM: $Mg/NaClO_3/TEA$

PRELIMINARY HAZARDS RANKING ANALYSIS AS USED TO GENERATE DECISION-MAKING INFORMATION ON THE EXPLOSIVE SAFETY OF PRODUCTION OPERATIONS

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Abstract

A systematic assessment of the hazards associated with explosive industrial operations at the Naval Ordnance Station, Indian Head, Maryland has been completed. This assessment was obtained through use of a Preliminary Hazards Ranking Analysis of each Special Job Procedure based upon input information obtained via a detailed questionnaire from experienced operating personnel.

A computer-assisted analysis resulted in the ranking of all explosive industrial operations by the relative degree of hazards associated with each operation. Of the 2,510 operations analyzed, a substantial number were found to be Category V, the highest hazard potential group. Of these, about one quarter are predicted to have a very high exposure factor during the next twelve months; a small number of these operations were identified where their Category V ranking was verified with a relatively high degree of confidence.

The analysis has accomplished the following:

- Generated a systematic review of all operations by operating personnel.

- Identified the most hazardous features of each operation for possible remedial action.

- Established a System Safety Data Bank on NAVORDSTA explosive operations.

- Produced a priority list for more detailed analyses.

- Provided a decision-making tool for management to judge the hazard potential of future operations.

Introduction

When an installation performs over 2,500 different industrial operations involving dozens of types of final and intermediate ordnance products comprised of many hazardous chemical ingredients, it is difficult for management to know if, where, and how the safety of these operations should be upgraded. At the Naval Ordnance Station, Indian Head, some of these operations have evolved over an 80-year period. New processes coexist with others like the production of single-base Naval gunpowder which has remained virtually unchanged since World War I. While the NAVORDSTA has pioneered in remote, automatic processing of hazardous materials, most processes still call for operating personnel to come in close contact with the materials at one point or another.

The nature and quantity of materials handled also is a variable with time. An empirical knowledge of hazards common

to standard double-base formulations has been gained over the years and this forms the basis for many existing operating procedures. As these formulations are made more energetic, accepted practice often becomes an unknown risk. Propellant types ranging from highly loaded solids to exotic liquid monopropellants diffuse the familiarity of operating personnel and strain both the hazard evaluation capability and the judgment of first-line supervision. In addition, the transfer of hazard data to process design and operating techniques occurs strictly within the realm of engineering judgment. Thus, in this setting, risk management is not a sometime thing but an everyday fact of life.

Given the above variability of operations, their associated risks and hazards, how does management achieve a goal of improving explosive safety within finite economic constraints? At the NAVORDSTA, a first step has been taken. Using the evolving tools of system safety analysis, a computerized assessment of explosive hazards has been made resulting in a ranking of operations by their level of short term risk. This study, called here a Preliminary Hazards Ranking Analysis (PHRA), has been performed to accomplish the following:

a. Identify the most hazardous feature of each operation for possible remedial action.

b. Generate a systematic review of all operations by operating personnel.

c. Establish a System Safety Data Bank on NAVORDSTA explosive operations.

d. Construct a priority list for further analysis.

Analytical Approach

The system was defined for purposes of this study as several sets of operations involving propellants, explosives, pyrotechnics, flammable solids/solvents and other hazardous materials in the process of physical or chemical conversion, measurement or testing, assembly or disassembly, transportation, packaging, storage, etc. Each individual operation is completely defined by a Special Job Procedure (SJP). The SJP is a document detailing each step of the operation; it provides personnel and explosive limits, designates facilities, specifies emergency procedures, and describes all personnel protection systems.

Operations are segregated into sets by their highest degree of hazard potential. The sets are constructed as Hazard Categories, defined as follows:

Category I - Those operations potentially capable of producing only equipment damage.

Category II - Those operations potentially capable of producing a minor facility loss.

Category III - Those operations potentially capable of producing a major facility loss.

Category IV - Those operations potentially capable of producing personnel injury.

Category V - Those operations potentially capable of producing a fatality.

The immediate objective established for the Preliminary Hazards Ranking Analysis was to identify all operations within Category V and to provide some ranking of those by their inherent hazard potential.

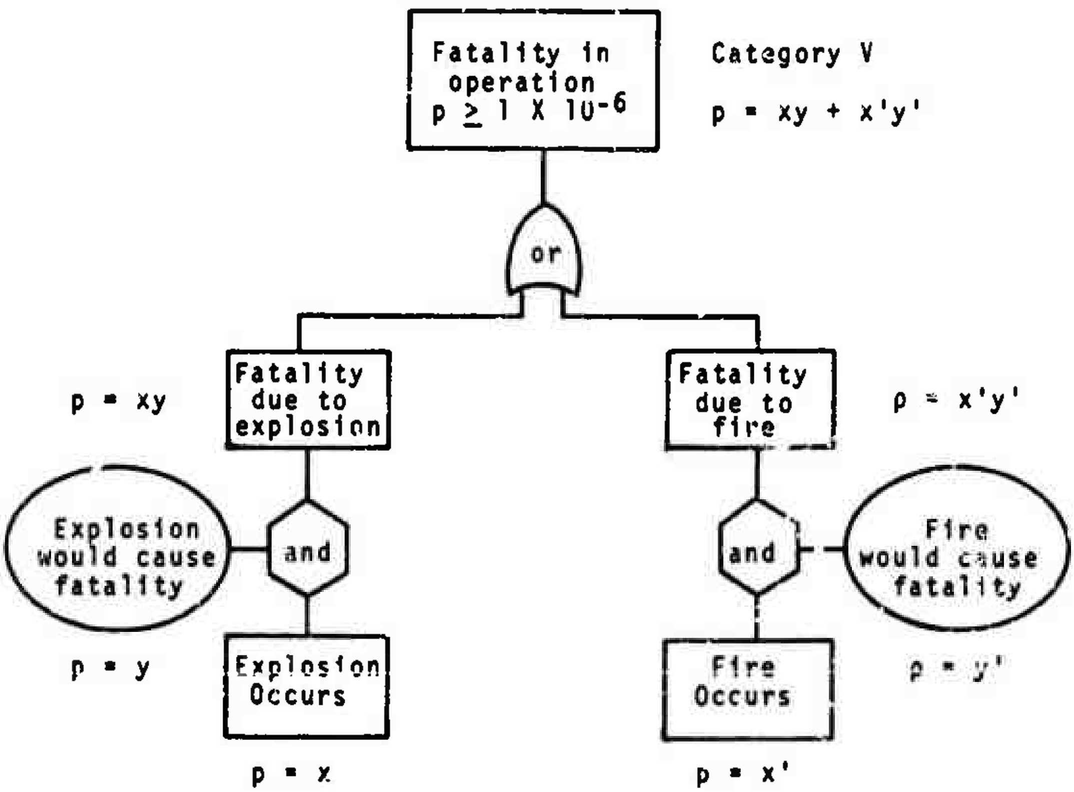
Only fire and explosive hazards have been considered in this analysis. This stems from the premise that to combine industrial and explosive safety objectives in one program serves only to weaken both. To examine only inherent hazards, it was necessary to further simplify the analysis by eliminating human error and equipment failure as possible contributing conditions. It is not that these vital factors can ever be disregarded; strong justification can be made for conducting a separate detailed analysis to determine the impact of human error and equipment failure upon inherent hazards. This would identify specific areas for increased inspection, training, and more sophisticated personnel protection systems. The Preliminary Hazards Ranking thus provides a means to pinpoint operations where this detailed analysis (referred to here as an Operating Hazards Analysis) is most urgently needed.

Recognizing that every explosive operation has some potential for producing a fatality, it was necessary to specify

some threshold or cut-off probability below which such an event can be considered exceedingly improbable. For several rather arbitrary reasons, this benchmark probability was established as 1×10^{-6}.

The fault-logic diagram in Figure 1 shows the Category V critical-event relationships which in turn outline the requirements for input data.

Figure 1



FAULT-LOGIC DIAGRAM

NOTE: The above algebraic relationships presume all events are independent and that all associated probabilities are very small.

Input data which specify the probability for fire or explosion and allow some judgment as to the adequacy of personnel protection systems (see Figure 2) were expeditiously obtained through the use of a detailed questionnaire consisting of 200 questions. Because of the large number of operations being analyzed, it was further necessary to design an extensive computer program to test the adequacy of the input data prior to analyzing for the contributing critical events.

Input

The PHRA questionnaire was designed to obtain YES/NO information from responsible operating personnel. The questionnaire was directed primarily toward two particular situations; the most hazardous step of the operation (defined as that step where an inadvertent initiation is most probable) and the step where the operator(s) is/are closest to the hazardous material (presumably where protection systems may be least effective).

Questions were included to provide three basic types of data:

a. Probability values for critical events such as accidental initiation of hazardous material, explosion, fire, and sympathetic reaction.

b. Factual data concerning the type, quantity, and sensitivity of hazardous material; the number of operators,

Figure 2

A GENERALIZED PERSONNEL PROTECTION SYSTEM

Isolation Subsystems	Mollification Subsystems	Shelter Subsystems	Preservation Subsystems
Remote Automatic Controls	Pressure Reliefs	Protective Walls	Protective Clothing Against Heat and Fragments
Interlocks	Blast Diverters	Barriers	Quick Egress and Escape
Warning Lights, Signs, etc.	Deluge and Sprinklers	Barricades	Medical Aid
Minimum Human Involvement	Blow Out Walls and Panels	Dead Spaces and Distances	Rescue Teams
Process Anomaly Remote Detectors	Automatic Shut-down of Equipment	Shields	
Personnel are Precluded from Exposure to Potential Effects	Effects from Energy Inadvertently Released are Minimized	Personnel are Shielded from Actual Effects	Personnel Exposed to Effects are Saved

supervisors, and observers present; and the protection afforded them during various phases of the operation.

c. Reliability of protective equipment such as interlocks, sprinkler/deluge systems or automatic shutdown equipment.

Program

A computer program was prepared to analyze the input data from the questionnaire. "YES/NO" answer combinations (test strings) were developed to serve various functions in the analysis.

a. Category C test strings indicated that input data are improper or contradictory.

b. Category V test strings indicated that the probability for a fatality in an operation exceeds 1×10^{-6}.

c. Category N test strings indicated a high rate of personnel exposure among Category V operations.

Category C strings check for inconsistencies within a question, when more than one "YES" answer is incorrectly given, or between questions, e.g., one answer indicated that the operator is shielded by a concrete wall when other answers indicate that no shield is present.

The fault-logic diagram shown in Figure 1 indicates how the fatality probability is developed for the Category V test strings.

Answer combinations have thus been formed represented by the probability products for explosion or fire (X or X') and fatality in the event of an explosion or fire (Y or Y'). Probabilities for fire and explosion are direct inputs from the answer sheet. For personnel protection, the assumption was made that the probability for having a fatality could still be 1×10^{-6} if only the minimum required protection exists. Criteria for construction and shielding to provide adequate personnel protection are stated in the NAVORDSTA safety manual. If little or no protection exists, the probability of a fatality approached one for every fire or explosion. When the protection is significant but below that required, then intermediate fatality probabilities were assigned.

As an example, a test string was developed to describe the following (XY) situation which would result in a Category V operation, i.e., $P_{xy} \geq \frac{1}{10^6}$.

> Probability for explosion is $.01<X<1$ during the most hazardous step of the operation as stated by the responder on the answer sheet. No automatic sprinkler, deluge, or shutdown system was indicated, which would interrupt the transition from initiation to full explosion, the probability should be in the upper portion of the range, approaching 1.
>
> Probability for fatality in the event of an explosion is $Y \geq 1 \times 10^{-6}$. The responder indicated that material is

Class A, 1-10 pounds are within the work space, operator is in an adjoining bay during the most hazardous step, and protected by one 12-inch reinforced concrete wall. This is the minimum requirement specified in the NAVORDSTA safety manual.

Category N operations are those which meet Category V criteria and involve a high rate of hazard exposure; over 50,000 times in the next year. The Category N strings were formulated as follows:

$N = N_p \times N_e \times N_o$

where

N_p = number of personnel exposed per operation

N_e = number of hazard exposures per person

N_o = number of operations forecast for the next twelve months

The probability for a fatality occurring each time a Category N operation is performed is not necessarily greater than other Category V operations; however, the probability of having a fatality within the next year is likely to be greater. This allows a ranking of Category V operations with Category N operations having the higher hazard priority.

Findings

A great deal of the first input data received was screened by the computer and found to be inconsistent or deficient in some respect. However, with the aid of operating personnel, the input was modified until a complete categorization was obtained on all current explosive operations.

A substantial number of the NAVORDSTA current explosive operations was found to meet Category V criteria though only 25 percent of these involved high hazard exposure (Category N).

The number of answer combinations programmed as Category V strings found in each set of input was printed as program output. Since each of these represents a discrete critical-event probability combined with a corresponding personnel protection scheme, every such combination found in the input adds to the relative confidence that the operation is within Category V. This is not to say that each string is a different explosion or fire event possibility, but rather a logic string leading to that conclusion. Thirty-eight operations placed in Category V with a high hazard exposure rate, were found to have input corresponding to 25 or more Category V strings. These operations then were deemed most likely to cause a fatality in the next year.

The Preliminary Hazard Ranking Analysis has, in the manner described, identified a small number of industrial operations for further analysis to determine what specific steps can be taken to reduce hazard potential. In addition, an Operating Hazards Analyses can be performed on all Category V operations in order to learn how this potential is increased by human error or equipment failure Future operations can hereafter be examined with the PHRA to provide a meaningful comparison of their hazard potential with that of existing operations.

Management now has a systems analysis tool to show the measure of risk associated with each operation, which implies corrective measures needed and most importantly, points out where remedial action should be taken first.

CURRENT U.S. ARMY RESEARCH ON

THE ANALYTICAL CHEMISTRY OF EXPLOSIVES

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Army research on the analytical chemistry of explosives is performed primarily at Picatinny Arsenal. The areas to be covered in this presentation are those being pursued at the Explosives Division involving advanced techniques in the identification and measurement of species at gross to trace levels, with emphasis to be placed on instrumental methods of analyses at the trace levels. These areas are outlined in Figure 1. The capability in these advanced techniques of analyses will then be related to the effort on the identification of explosives and their fragments and the detection of hidden explosive systems.

1. Neutron Activation Analysis (NAA) is conducted for the quality control of explosives and munitions items with either fast neutrons (FNAA) or with thermal neutrons (TNAA). For this work there are two types of neutron sources located at our facility:

Kaman Sealed Tube Neutron generator involving $^{3}H(d,n)^{4}He$, emitting 15 Mev fast neutrons at a rate of 5×10^{10} n/sec.

Two ^{252}Cf sources emitting 2.35 Mev fast neutrons at a specific rate of 2×10^{12} n/sec/g, with $T_{1/2} = 2.65$ years. One of these sources contains 4 micro grams ^{252}Cf having a rate of 8×10^{6} n/sec and the second 10 mg ^{252}Cf with a rate of 2×10^{10} n/sec. The second source is contained in a 5' diameter steel cask filled with 70% parafin wax, 5% polyethylene powder and 25% $LiOH \cdot H_2O$ which was designed at ED. This is shown in Figure 2.

A. FNAA is used for gross elements in explosives, propellants and related high energy materials. Applications of FNAA are briefly summarized:

(1) Total N content in pure organic exploaives. Analysis of total N in organic explosive is via the $^{14}N(n,2n)^{13}N$ reaction involving positron annihilation with emission of 0.511 Mev γ's of 10 min half life. Total nitrogen determinations of TNT, HMX and NC are shown in Figure 3. The nitrogen content is analyzed to within 0.1% of the calculated values which is comparable to wet chemical or pyrolytic methods. FNAA is rapid (ca. 10 min/analysis) and nondestructive, whereas the conventional methods are orders of magnitude more time consuming and destructive.

(2) Determination of uniformity of composition of binary mixtures is demonstrated in Figure 4. An assay of the octol composition in the LAW Warhead showing inhomogeneity in both horizontal and vertical planes was accomplished at an average rate of 10 minutes per sample as compared to three hours per sample by chemical analysis.

(3) N&F determination in energetic binders (FEFO).

(4) Neutron gauging of weight changes of explsovie charges in sealed items.

(5) Neutron Radiography - Rocket warhead boosters and explosive destructors have been assayed where x-ray radiography has failed. This is based on the fact that metals are relatively transparent and organic materials are not to thermal neutrons which is the opposite case with x-rays.

B. TNAA. The energy of the fast neutrons emitted by the 10 mq ^{252}Cf source is thermalized to 0.02 Kev at a flux of 10^{8} n/sec/cm^2. These neutrons are used for:

Analysis of trace quantities of Mn, Al, Na and Cl in explosives for the purpose of relating elemental trace impurity profiles to source of supply.

C. Moderation of Fast Neutrons.

Moisture content of explosives down to the 0.1% weight level can be determined non-destructively.

II. Spark Source Mass Spectrometry

The technique of spark source mass spectrometry is being developed for the determination of the origin of manufacture of explosives by their specific trace elemental impurity profiles. The instrument (Fig. 5) employed for this purpose is an Associated Electronics Inc. (AEI) MS702 Double Focusing Spark Source mass spectrograph equipped with electrical and photographic detection systems. The photographic detection system includes a Jarrel Ash densitometer for the automatic determination of mass intensities from print-outs by an oscillographic recorder. Both systems are adapted for magnetic scanning and peak switching. Trace impurities in the ppm level are attainable with an optimum accuracy of 30%.

(1) Preliminary analysis of RDX from Holston shown in Figure 6 indicates Zn contamination which is attributed to its use as a sacrificial anode for the protection of the teflon-coated stainless steel reactors. The

integrity of the teflon coating is questionable since the usual elements found in steel are present in this sample of RDX. Work will continue on samples from Canada, Great Britain, and other foreign countries.

(2) Analysis of 3 samples of AN is given in Figure 7. Contrary to the accepted contention, AN as an oxidant-reductant did not explode when sparked directly. Some of the results checked by atomic absorption are shown to be comparable. The apparent differences shown among the AN samples will be checked further and subjected to a statistical analysis.

(3) Analysis of TNT is shown in Figure 8. The trace impurity levels of Canadian TNT appears to be lower than that of the American TNT. Before proceeding further on comparisons involving foreign samples of TNT, work is underway to establish differences, if any, among the TNT lots produced by Radford, Joliet and Volunteer Army Ammunition Plants (AAP's).

III. Gas Liquid Chromatography (GLC)

Quantitative analysis in the ppm level by GLC involves operation at or near the limits of capability of the instrumentation and is, therefore considered difficult to perform. However, with sufficient emphasis on details controlling the numerous parameters affecting precision and appropriate selection of conditions for optimum resolution the task can be accomplished.

A Varian Aerograph, Model 30 and an F&M, Model 810 are concurrently being used to establish the parameters for the quantitative determination of trace molecular impurity profiles of organic explosives (initially of TNT), typical of their source of origin. (This effort is complementary to the trace elemental impurity profile determinations by spark source mass spectrometry.) Both instruments are equipped with flame ionization and thermal conductivity detectors, temperature programmed in dual column arrangement. DC gum silicone and OV type stationary phases are being used separately in each of the respective instruments.

For a satisfactory statistical treatment of the data to determine impurity profile differences of military grade TNT produced in the U.S., 150 samples, representing various lots from each of the three AAP's (Radford, Joliet and Volunteer) were the calculated minimum number required. A set of 15 samples (in duplicate), representing a single lot each from Radford and Volunteer show trends of differences in their respective isomer contents (Fig. 9). These trends are with the 2,4 DNT, 2,3,4 and 2,4,5 TNT isomers; where the Radford samples contain significantly larger quantities of the first two and lesser quantities of the last isomer impurity than the Volunteer samples.

The GLC procedure will be further developed for the more complete resolution of all of the DNT and TNT isomers, and as the data starts to evolve at a more rapid rate it will be programmed into the Arsenal's computer for processing.

The effectiveness of the GLC technique to fingerprint explosives is further illustrated in Figure 10. A sample of Russian TNT contains the 2,5 DNT isomer impurity at a concentration of approximately 1 ppt which is three orders of magnitude greater than the concentration in the U.S. TNT. This characteristic isomer impurity of Russian TNT could shed some light on their process of manufacture, or perhaps be used as a means of its identification in the field.

IV. Electron Spectroscopy for Chemical Analysis (ESCA)

Research involving the ESCA technique is being conducted with a Varian - IEES - 15 interfaced with a 4K Computer Memory Bank which averages, plots and stores data. This instrument. shown schematically in Figure 11, generates x-ray photons with an incident energy of 1253.6 ev. in a 10 second scan (one sweep). Usually 50 scans over a 10 minute period are required for an analysis. Energy depoaition is approximately 0.1 ev. total (50 scans) to a half-thickness depth of 20-40A. Based on the principle that discrete energies of electron emission are characteristic of the atom itself and of the atom in its various chemical combinations, both core and valence band electronic structure can be determined and molecules can be identified in their progressive states of disproportionation. The lower limit of detection of the ESCA technique is in the ppm region and thus far analysis have been on a semi-quantitative basis.

(1) Mode of RDX and HMX Decomposition - When RDX and HMX are subjected to UV and gamma irradiation the nitro nitrogen bond preferentially ruptures. Exposure of these compounds to slow thermal decomposition results in both nitro-nitrogen and ring nitrogen rupture with no residual product of decomposition formation. Whereas, thermal explosive decomposition results in the formation of a large residue consisting of both undecomposed and decomposed nitramines containing nitrogen in a high state of oxidation.

(2) Metal-Explosives Interface Reactivity - One of the more practical application of ESCA is the determination of the compatibility of various explosive-metal systems. Both the explosive as well as the metal under investigation can be analyzed concurrently and the chemistry at the interface thereby elucidated. Initial studies have been conducted with RDX on Au. Under the influence of UV irradiation, the Au was found to react with residual products of RDX decomposition. This is shown in Figure 12. There is a super-imposed shift of the 4f7 and 4f5 doublets indicative of bond formation.

V. Nuclear Magnetic Resonance (NMR) Spectra of Explosives

Previous studies on nitroaromatic compounds have revealed that the Varian TC-64 NMR instrument is an excellent tool for the routine identification of highly nitrated structures. In this initial study as many as twenty-five nitro aromatics have been fingerprinted. Based on the chemical shift and spin-spin coupling parameters, a spectrogram of any explosive can be provided by a few sharp signals. These simple spectra are in sharp contrast to the corresponding spectra generated by IR as shown in Figure 13. Hence, the principle components of composite explosives can be analyzed down to 0.1% concentrations by the NMR technique without recourse to chemical separation that would be required for IR analysis.

In essence, the ongoing activity cited above demonstrates a considerable advancement in our capability in the areas of quality control and trace analyses of explosives. Because of the relationship of this capability to the effort on detection and identification of explosives, (civilian as well as military), a symposium was held at PA on 5-7 October 1971 to determine, among other objectives, the extent to which this laboratory could contribute towards the solution to problems of mutual interest. As a consequence of this symposium the ED has underscored and redefined its efforts on the trace analysis of explosive in the categories of identification and detection of explosives.

VI. Identification of Explosives and Explosive Fragments

(1) The identification of the origin of manufacture of military explosives both U.S. and foreign by their elemental and molecular impurity profiles will be extended to include commercial items, both domestic and foreign.

(2) Identification of explosives and their fragments on metal surfaces is routinely accomplished by IR, TLC, GLC, and wet chemical methods. Sample specimens are extracted with solvents resulting in some cases, in cross contamination of critical areas and the removal of the contaminant from the surface and hence the evidence. In those cases where the size of the sample specimen is limited, the analysis can be performed by ESCA with trace quantities nondestructively. ESCA can also supply information on the various oxidative states of nitrogen imbedded in the metal surface layer after an explosion.

Sample fragments from the scene of an explosion in San Mateo, California were analyzed by IR and ESCA methods. Nitramine and nitrate type compounds were identified by IR and ESCA, linear nitrate esters and TiO_2 were more specifically identified by ESCA.

Empty shells which presumably had never been used, exploded on heat-treatment at 500°C. Examination by ESCA of the fragmented metal surfaces revealed the presence of TNT and lead (possibly from paint). The presence of TNT was verified by IR.

(3) A new project has been initiated dealing with the development of wet chemical methods of identifying explosives and their fragments. The aim of this work is to develop analytical techniques that are simple and reliable for the incorporation into a portable field testing kit. For this pur, 'e, the avenue of thin layer chromatography has been explored.

A conventional TLC apparatus is shown in Figure 14. It is apparent that the size does not lend itself to being portable.

The thin layer chromatographic devices contained in the Kodak Chromat/O/Screen Analysis Kit for Alkaloids, shown in Figure 15, were selected for their portability and stability of adhesion of the silica-gel to the mylar strips.

Gels of the appropriate solvents for the various explosives and visualization sprays have been developed thus far for the separation and identification of TNT, TNB, Tetryl, HMX or RDX. The gels are made up of Silinox Hydrophobic Fumed Silica or Thixotropic Gel Powder and with either benzene, chloroform, acetone or their mixtures, depending on the R_f values required for the explosive. The visualization indicators consist of alkaline acetone, ethylene diamine, morpholine or Franchemont solution.

The separation of TNB, TNT and Tetryl is shown in Figure 16 and the separation of TNT, Tetryl and RDX is shown in Figure 17 Although the separation and identification of poly nitro aromatics in general have been reported by the conventional TLC technique, its adaptation in the form of a portable kit is considered an innovation. This work will be extended to include the identification of other military and commercial explosives and pyrotechnic compositions.

VII. Detection of Hidden Explosives by:

(1) FNAA without additives. Work was initiated on the detection of hidden explosives by activation of their N-O content with the 14 Mev neutron generator. Based on the assumption that the N/O ratios of explosives are significantly different than those of background materials, the corresponding induced radiation could be indicative of the presence of explosives in luggages or packages. The current approach is to look at both radionuclides, according to the following reactions:

$$^{14}N(n,2n)^{13}N \rightarrow 0.511 \text{ Mev } \gamma \; (T_{1/2} = 10 \text{ min})$$

$$^{16}O(n,p)^{16}N \rightarrow 6.1 - 7.1 \text{ Mev } \gamma \; (T_{1/2} = 7.5 \text{ sec})$$

Two 3" x 3" Sodium Iodide (Tl activated) crystals were used in various geometric arrangements for optimum detection.

The results of preliminary experiments done by 15 seconds irradiation with fast neutrons are shown in Figure 18. The ratios of N and O in the air to the N and O in RDX are both 1/4. Only the gamma activity of either N or O, but not of both, for any one of the background materials is shown to equal or approach that of RDX. Hence, these materials do not interfere with the detection of RDX. This method of detection has distinct possibilities and is being investigated with other explosives and background materials.

(2) TNAA with additives (inert) - An exploratory investigation using Gd in the form of a coating on the metal of a blasting cap and on the wrapping of dynamite sticks has indicated the technical feasibility of the method. The Gd is sufficiently activated by the 4mg ^{252}Cf source, emitting 8×10^6 n/sec. The induced emissions of prompt gammas from the doped dynamite wrapping are more readily discriminated from the competing background signal than the emissions from the coated metal capsule. This method bears similarity to the "Sense Trace Method" developed by Astrophysics Corp. for the detection of stolen securities.

In conclusion, some immediate objectives should be mentioned.

i) A high performance liquid chromatography apparatus is on order for the identification of thermally unstable and high-melting solids.

ii) A chemical ionization MS coupled with a dedicated GLC and mini-computer is being acquired for the analysis of complex mixtures of organic explosives and for the accumulation and storage of mass spectra of explosives.

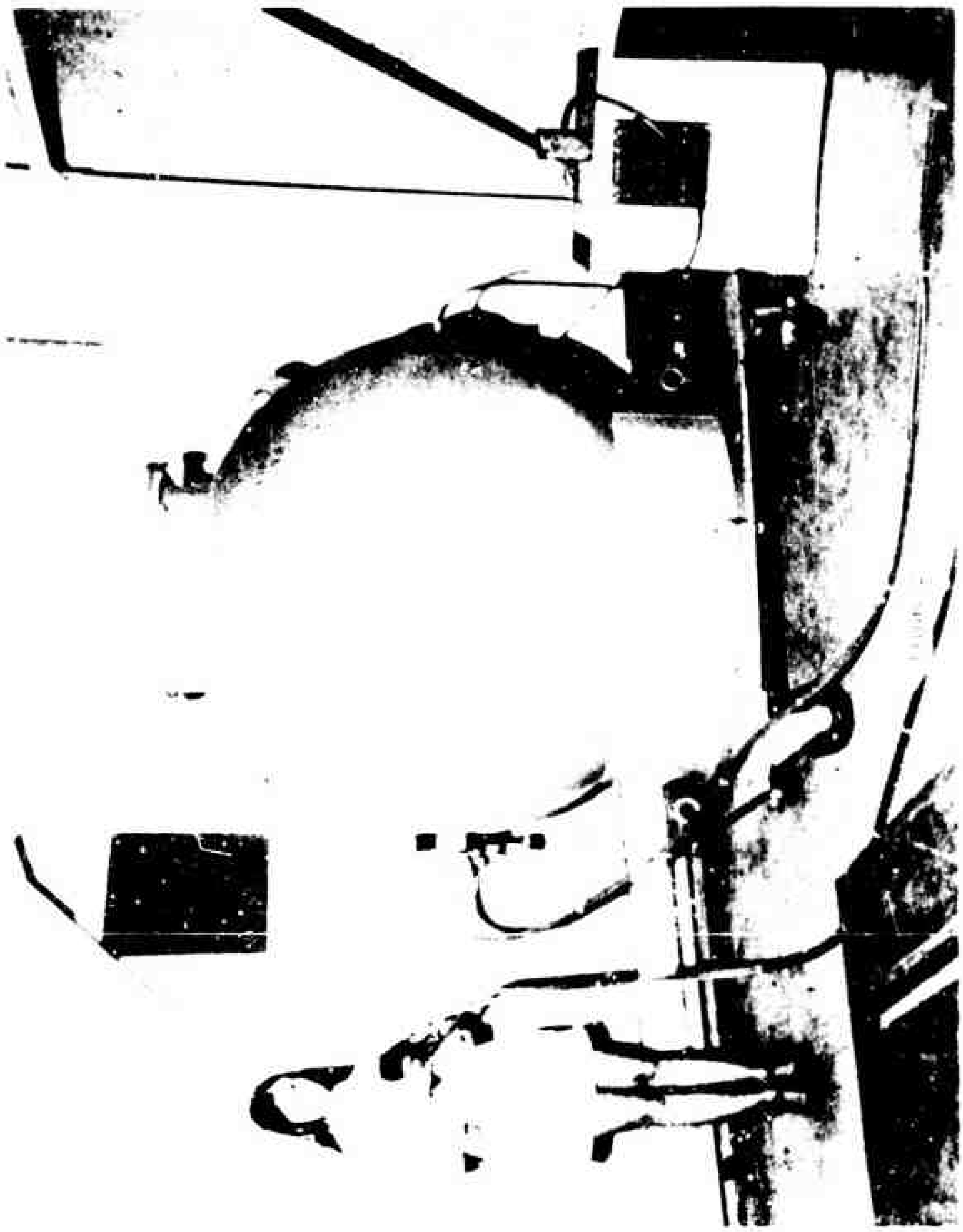
iii) The mini-computer concept will be applied to the other instruments used for analysis for the purpose of establishing a date bank on explosives.

iv) Cooperation and assistance will continue to be extended to the Law Enforcement Agencies at the Federal, State and Local levels for the exploration and solution of current mutual technical problems in the analysis, detection and identification of explosives and their fragments.

ADVANCED TECHNIQUES IN THE ANALYSIS OF EXPLOSIVES

	Technique	Application
I	Neutron Activation Analysis	Gross and Trace Elemental Determinations Uniformity of Binary Mixtures Weight Changes in Sealed Items Neutron Radiography Moisture Content
II	Spark Source Mass Spectrometry	Trace Elemental Impurity Profiles
III	Gas Liquid Chromatography (GLC)	Trace Molecular Impurity Profiles
IV	Electron Spectroscopy for Chemical Analysis (ESCA)	Mode of Decomposition of Organic Explosives Metal-Adsorbate Interactions
V	Nuclear Magnetic Resonance (NMR)	Spectra of Nitrated Aromatics Resolution of Composite Explosives

Figure 1



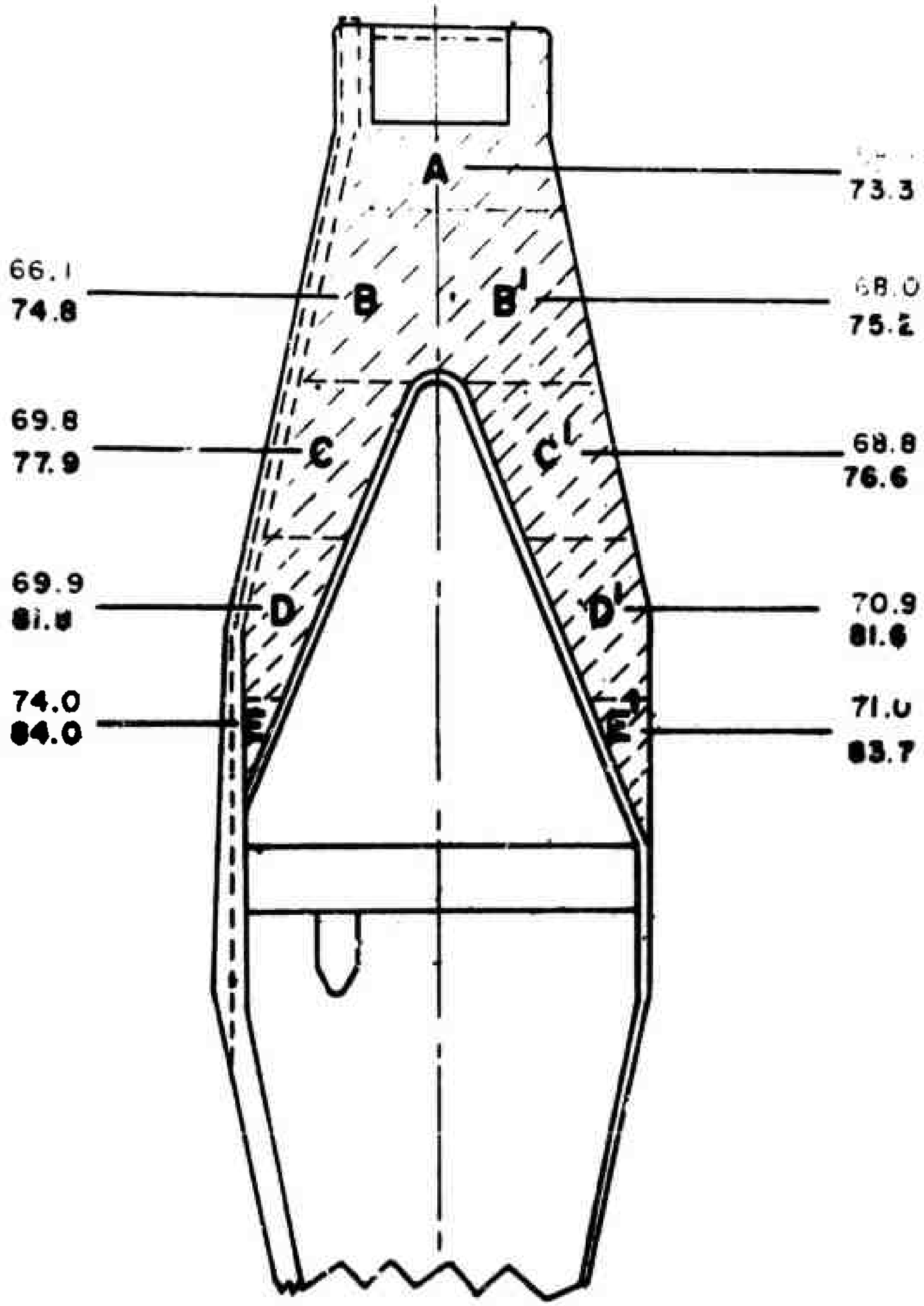
TOTAL NITROGEN CONTENT BY FAST

NEUTRON ACTIVATION ANALYSIS

Sample	Percent Nitrogen	
	Wet Chemical	Neutron Activation
Nitrocellulose	12.60	12.57 ± 0.05
Nitrocellulose	12.18	12.12 ± 0.10
Nitrocellulose	13.11	13.03 ± 0.07
Nitrocellulose	13.23	13.23 ± 0.06
TNT	18.50 *	18.50 ± 0.06
HMX	37.84 *	37.78 ± 0.06

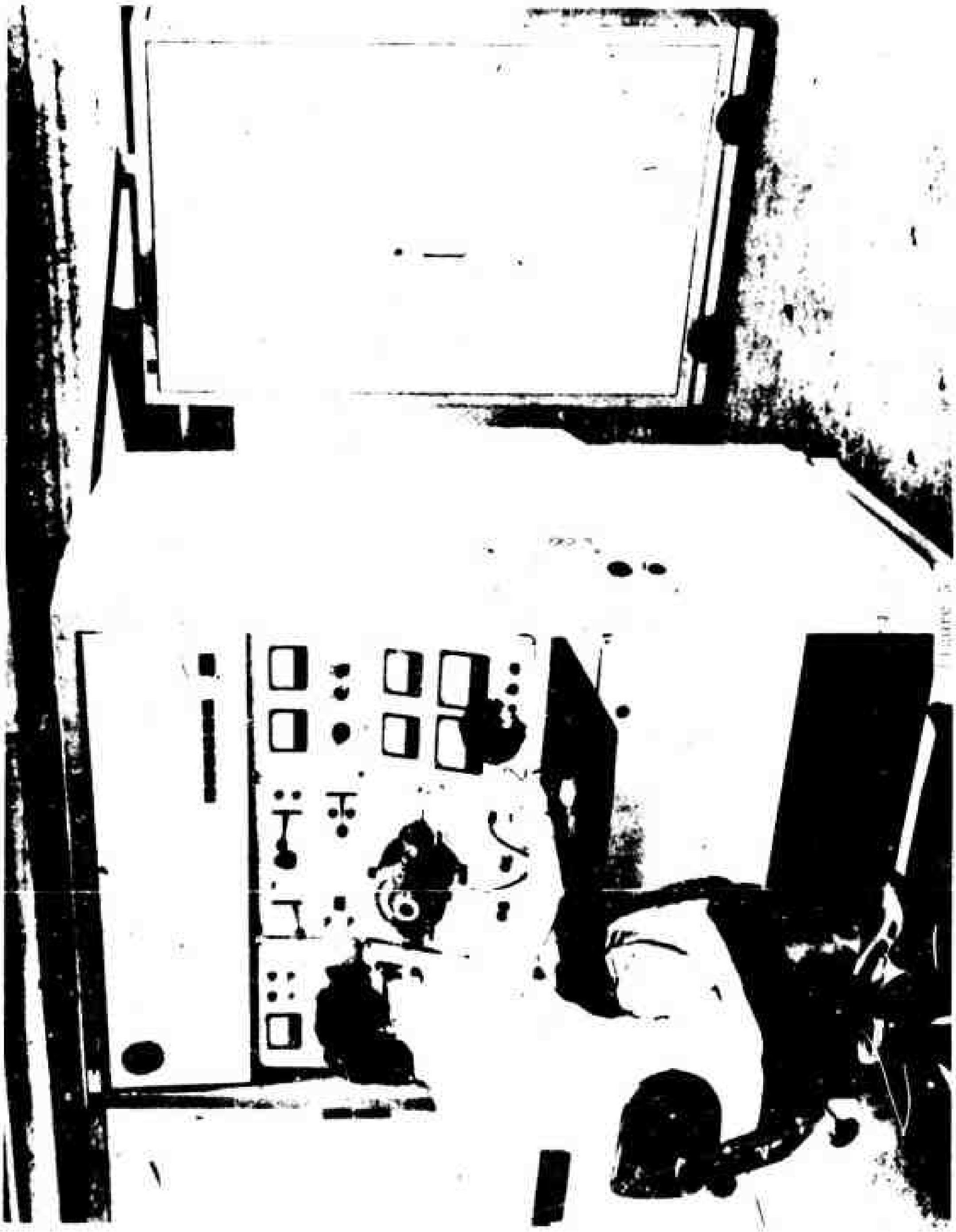
*Theoretical

Figure 3



HMX CONTENT IN LAW WARHEADS

Figure 4



ANALYSIS OF HOLSTON RDX

Element	Conc. ppm (W)
Boron	1.1
Fluorine	16.6
Sodium	87.0
Sulfur	84.0
Silicon	1.5
Potassium	84.0
Calcium	86.0
Titanium	21.5
Chromium	3.0
Iron	97.0
Nickel	3.8
Zinc	52.0
Copper	6.0
Molybdenum	7.4

Figure 6

ANALYSES OF AMMONIUM NITRATE

Element[1]	Recrystal'd Lab Sample	Commercial Samples Co A	Co B
Boron	NO	1.2	0.1
Sodium	0.9	0.9	0.7
Magnesium	2.4 (3.0)	10.0	2.2
Aluminum	0.7 (1.0)	9.8	24.0
Silicon	8.0	650.0	150.0
Phosphorous	1.8	NO	NO
Sulfur	2.0	NO	NO
Potassium	0.8	3.3	2.4
Calcium	7.2 (4.0)	3.6 (5.7)	2.4 (3.0)
Manganese	0.2	3.1	0.1
Iron	36.0	140.0	11.0
Copper	0.7	1.6	7.0
Zinc	0.8	0.5	3.0
Cerium	0.3	3.5	2.5
Cesium	3.6	27.0	11.0
Barium	0.1	0.1	1.2
Lanthanum	0.3	3.5	2.4

[1] Concentrations in ppm(w)
Values in parentheses by atomic absorption

Figure 7

ANALYSES OF TRINITROTOLUENE

	American ppm (w)	Canadian ppm(w)
Boron	0.3	ND
Fluorine	2.1	2.0
Sodium	2.4	ND
Magnesium	7.1	14.2
Aluminum	36.0	1.1
Silicon	50.0	45.0
Phosphorus	2.1	ND
Sulfur	7.5	ND
Potassium	2.6	23.0
Calcium	24.5	22.0
Titanium	1.0	1.0
Chromium	0.1	0.3
Manganese	0.1	0.7
Iron	26.0	23.4
Cobalt	0.07	0.7
Nickel	ND	3.1
Copper	0.3	1.0
Zinc	1.5	4.4
Lead	13.6	1.4

Figure 8

GLC[a] ANALYSIS OF MOLECULAR IMPURITIES IN TNT[b] FROM DIFFERENT SOURCES

Isomer	Volunteer (Percent x 10^3)	Radford[c] (Percent x 10^3)
2,6 DNT	0.6	4.5
2,5 DNT	0.5	11.2
2,4 DNT	20	130.4
3,5 DNT	1.5	17.1
3,4 DNT	0.4	Trace
2,4,5 TNT	47.2	8.8
2,3,4 TNT	1.9	78.1

(a) Varian Aerograph 1800, programmed at 100-225°C; DC gum silicone stationary phase, He carrier, flame ionization detector; analysis in 30 minutes.

(b) A set of 15 samples, in duplicate, representing a single lot each from each of the AAP's.

(c) Also contains trace amounts of o-nitrotoluene.

Figure 9

Impurities Detected in TNT by Gas Chromatography (F.I.D.)

Volume injected: 10 µl acetone solution (200 µg TNT/1 µl acetone)

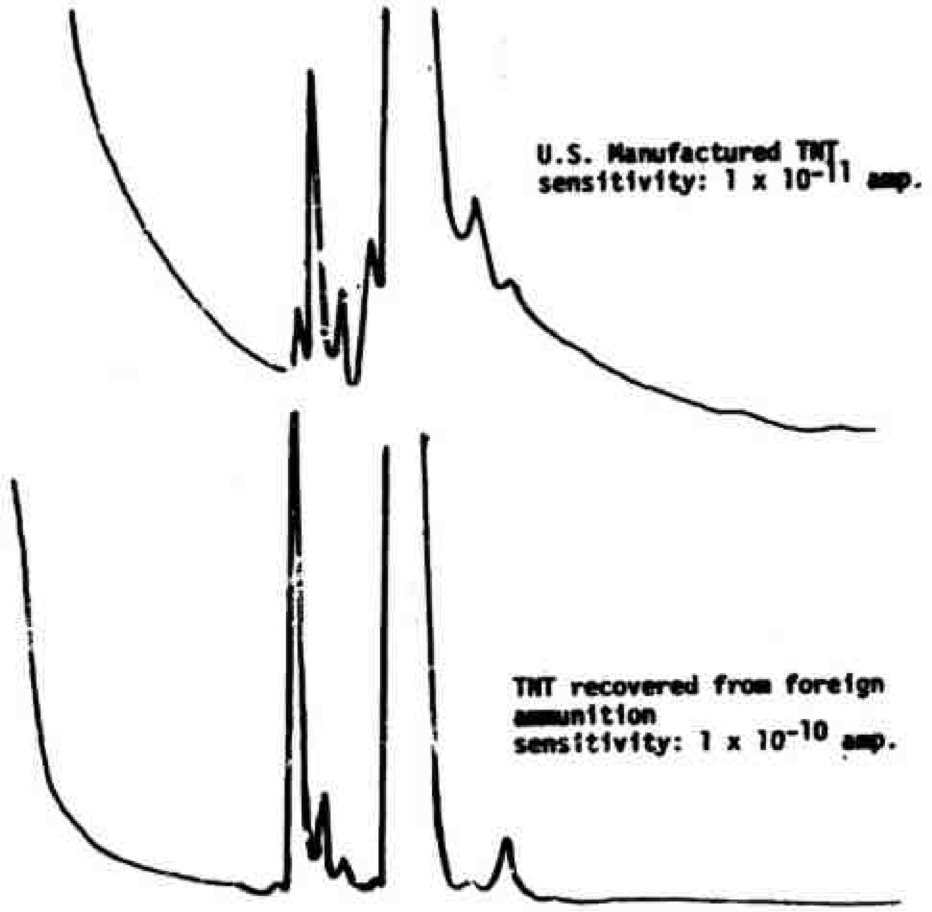
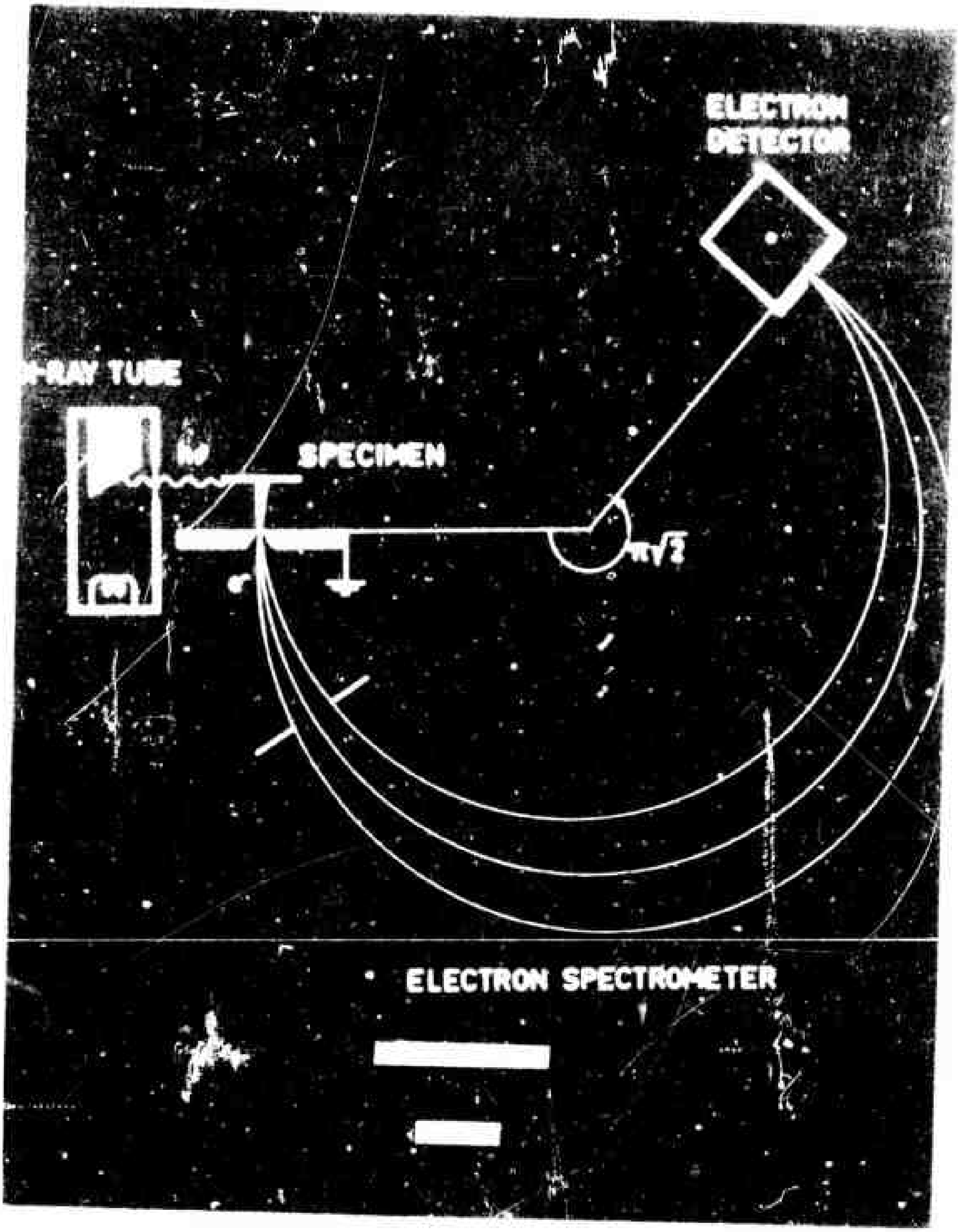


Figure 10



ELECTRON DETECTOR
-RAY TUBE
SPECIMEN
ELECTRON SPECTROMETER

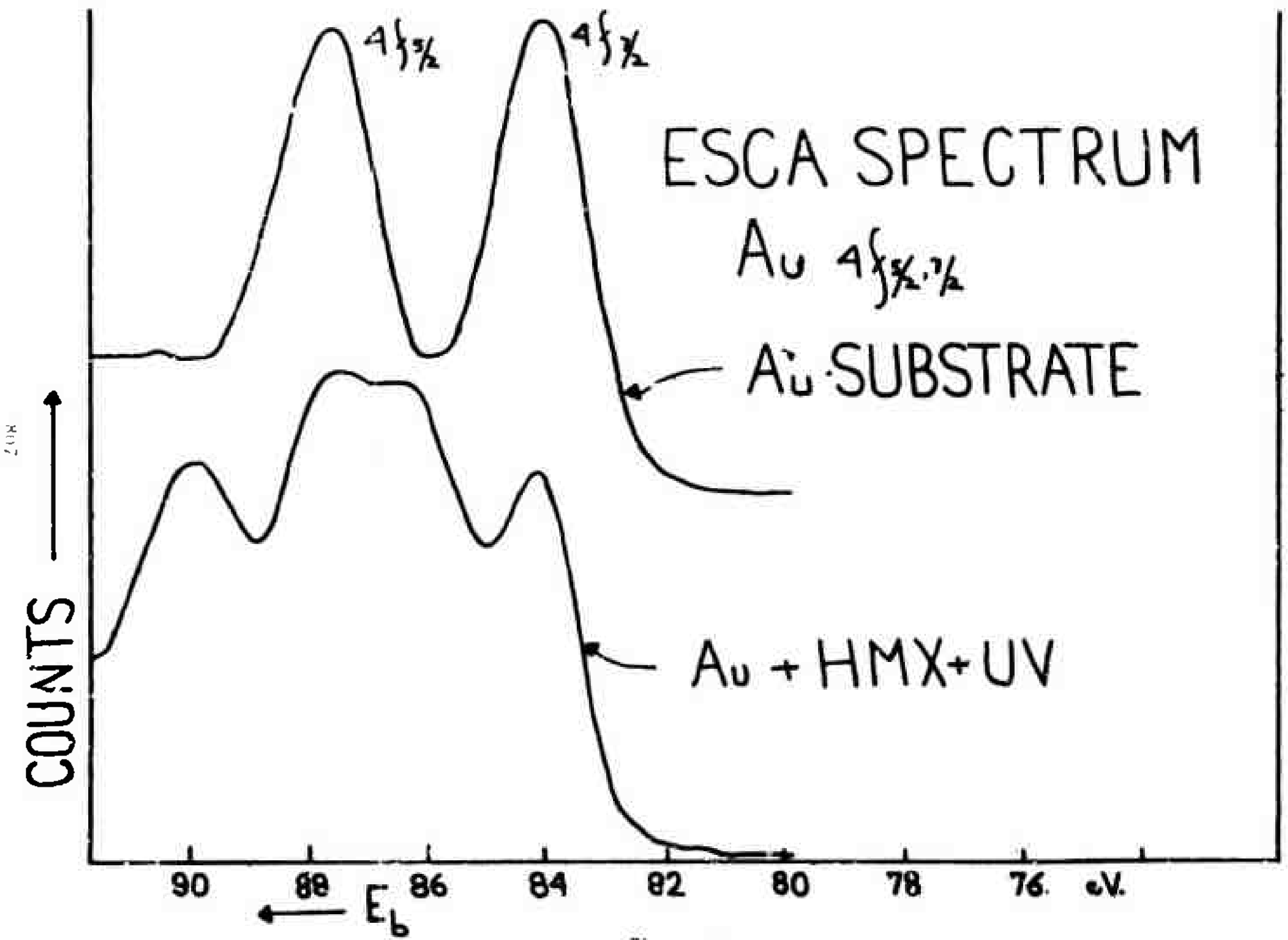
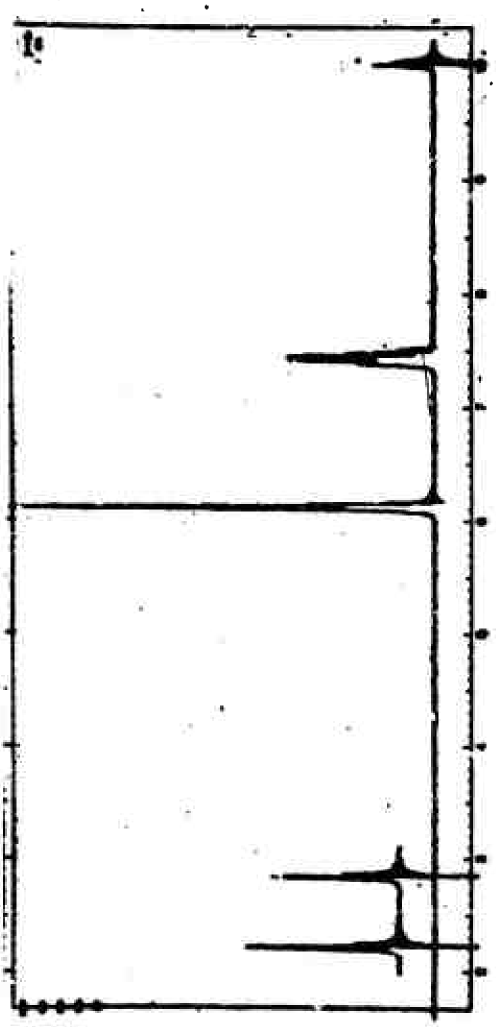
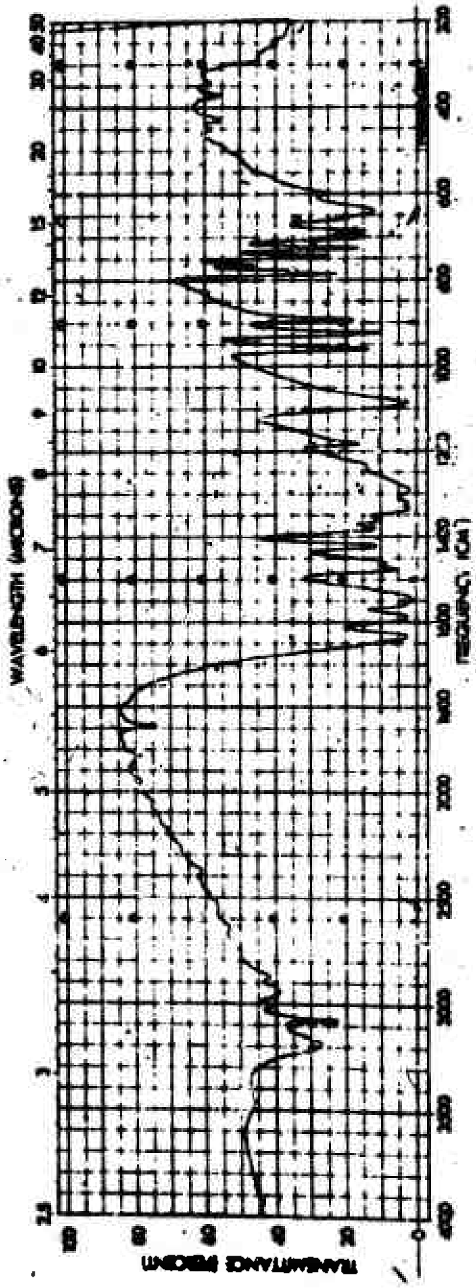

ESCA SPECTRUM
Au 4f 5/2, 7/2
4f 5/2
4f 7/2
Au SUBSTRATE
Au + HMX + UV
COUNTS
90
88
86
84
82
80
78
76
eV.
E_b

Figure 12





Figure

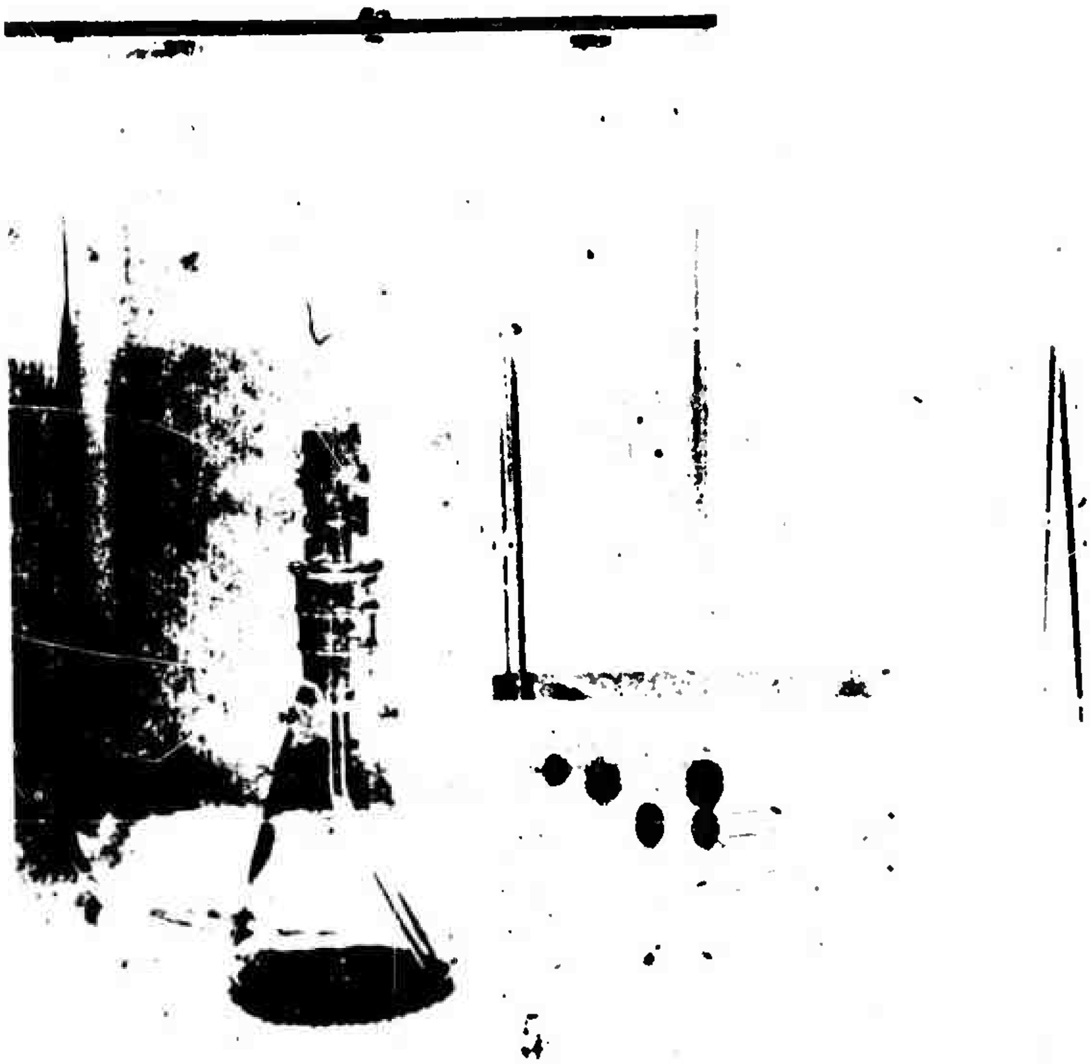


Figure 14

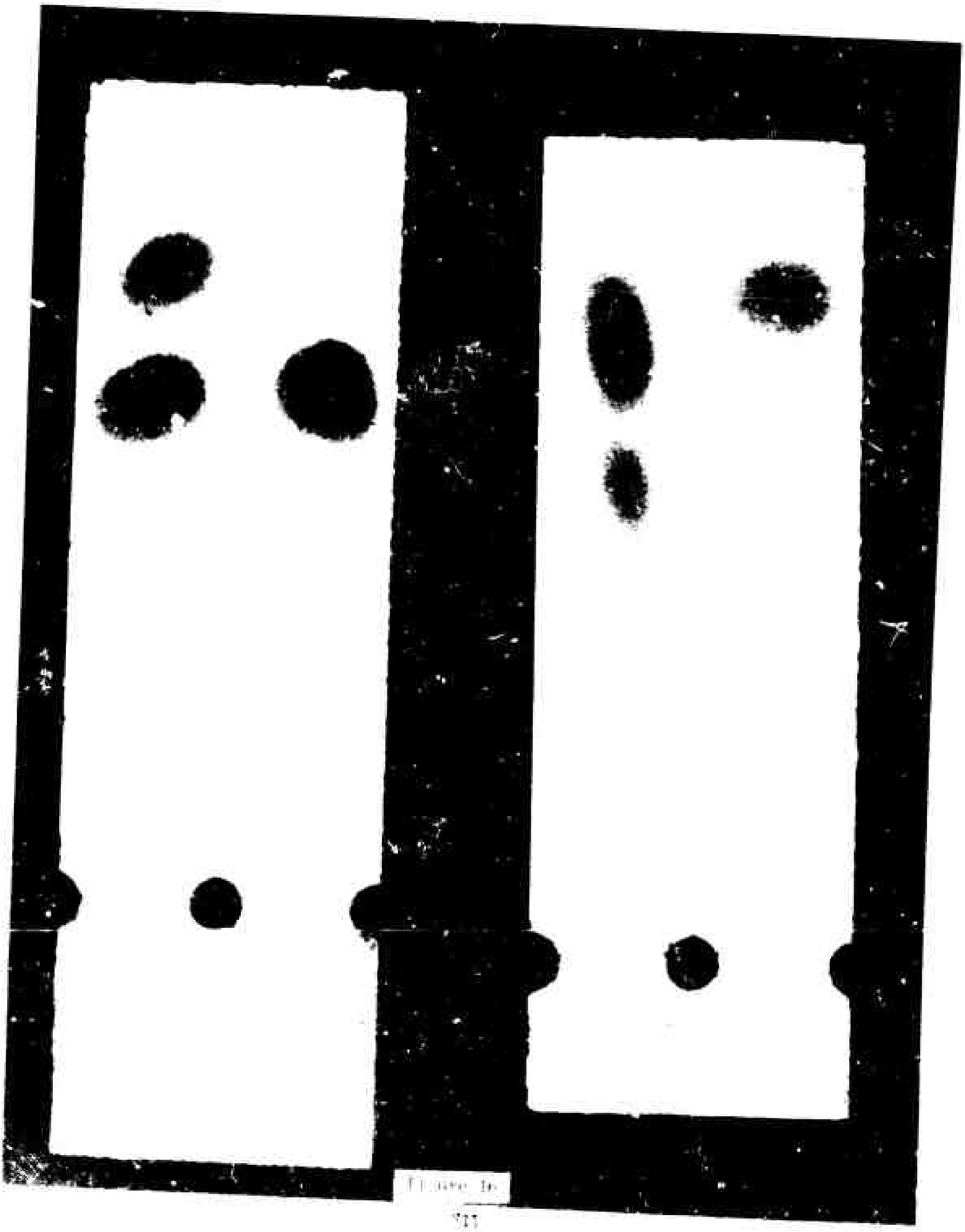


Figure 16

Figure 17

DETECTION[a] OF EXPLOSIVES (RDX)[b] BY FNAA

Irradiated[c] Systems ($5x10^{10}$ n/sec)		Ratio of Gamma Activity[d] — Nitrogen (0.511 Mev-$T_{1/2}$=10m)	Ratio of Gamma Activity[d] — Oxygen (6.1-7.1 Mev-$T_{1/2}$=7.5 sec)
Plastic Suitcase (18"x12"x5")	Empty/RDX	1/4	1/4
	450g $NaHCO_3$/RDX	1/5	4/5
	Cotton/RDX	1/4	3/4
Cowhide Suitcase (23"x18"x8")	Empty/RDX	1/4	1/4
	Cotton/RDX	1/4	3/4
	400g Cu/RDX	1	1/5

(a) 2 - 3"x3" Sodium Iodide (Tl activated) Crystals

(b) 800g Samples

(c) 15 Seconds Duration

(d) 10-15K Counts per Minute Range

Figure 18

STANDARD PROCEDURES FOR APPROVING EXPLOSIVES FOR U. S. SERVICE USE

By

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H. J. Gryting, Naval Weapons Center, China Lake, California

The Director Defense Research & Engineering in a 1969 memo to the assistant secretaries for R&D directed the services to establish "Standard Performance Acceptance Specifications for the Qualifications of a Military Explosive". More recently they have asked for a U.S. tri-service explosive program in lieu of individual service programs. At the time of the first request the Navy had a good start on what is now the Navy Qualification document OD44811 "Safety and Performance Tests For Qualification of Explosives" of January 1972 (Reference 1). The first preliminary version of a U. S. tri-service manual was prepared in September 1971 (Reference 2). This is undergoing revision for release to all U. S. services. It will be made available also for purchase by contractors through the Superintendent of documents.

The department of defense has separate explosives programs under the cognizance of each of the three services. These programs support the Army, the Navy and the Air Force with their new explosives according to their sometimes varied needs.

As these programs are productive, new explosives are generated in response to goals set to obtain improved explosives to satisfy future ongoing needs. Some of these may be of high interest to consider for concurrent development with warheads for missiles or other applications programs. Such explosives may have been selected in the past for further development toward a specific weapon before the necessary information had been obtained. Some promising explosives have been shelved before either sufficient information had been obtained or a logical application had been found. When such application later appeared it is discovered that there is insufficient information available to determine probable suitability of the explosive for investigation for that application. The capabilities and limitations of the explosive have not adequately been determined.

If standards are set up for interim qualification prior to selection for specific applications (at which time further modification may be desirable), past efforts in explosive development can be better utilized to solve current problems.

The document (Reference 2) presents a compilation of test procedures from the three services that have been agreed upon for qualifying primary, booster, and main charge explosives for consideration for use in service applications and in development programs leading to such applications (interim qualification) and also those test procedures and criteria for evaluation of explosives for final qualification of the explosive in its intended application. These qualification procedures will henceforth be required for any explosive to be used by any of the military services.

Some of the tests are listed as mandatory and must therefore be performed. For these, suggested passing criteria have been established and are presented. It is accordingly expected that these criteria will be used by all services. The individual service reserves the right to change the passing criteria to fit their own perhaps more stringent requirement in specific cases or to devise more appropriate criteria.

<u>Relationships of organizations in the three services to the approval of explosives and of explosives in weapons.</u>

Although the required tests for qualification will be the same or nearly so except for occasional more stringent requirements for certain applications, the three services individually qualify the explosive they use. For the Navy the ordnance systems command has full responsibility for explosives development and qualification both interim qualification and final qualification which is in the weapon where applied. The Explosives and Pyrotechnic Branch, ORD 0332 is responsible for making recommendations for approval to COMNAVORD whereas the Safety Division ORD 048 has overall weapon systems safety responsibility per NAVORDINST 8020.11 (Reference 3). The Weapons Systems Explosives Safety Review Board must approve of every Navy weapon prior to its release for service use (Reference 4). Further delineation of Navy responsibilities in NAVORD are given in several instructions summarized in NAVORD INST 8020.11 (Reference 3), included in the manual and in NAVMATINST 8020.1D (Reference 4).

For the Army, interim qualification is granted by the Explosive Division, Feltman Research Laboratory (FRL) Picatinny Arsenal, Dover N.J. This qualification will be granted on the basis of successful passing of required tests of OD44811 snd its tri-service successor and any other tests from the background information sections of the manual that the Explosives Division deems necessary. Finsl qualification requires WR-5D (Reference 5) type tests as indicated in the tri-service manual (and OD44811) and in addition those tests required for special applications from the publication "Army Materiel Tsst Procedures". (Reference 6). This is a rather large group of booklets which cover specialized tests for various Army applicstions. Procedure 4-1-001 describes cognizant Army Agencies and offices for weapons systems ammunition and explosives for their life cycle. Environmental tests are covered in more detail in AR 70-38. A large number of these test procedures are the same MILSTD 810B and MILSTD 331 procedures referred to in WR-50. The final explosives approval and qualification in the munition is givsn by the Army Munitions Command.

The Air Force grants interim explosives qualification through its Air Force Armament Laboratory, Eglin Air Force Base, Florida and final qualification through the Air Force Non-Nuclear Munitions Safety Group (NNMSG). The Air Force requires the use of the same evaluation procedures as the other services, viz., the tri-service manual (Reference 2), (with OD44811 (Reference 1) being used until the tri-service version is issued).

General information on requirements for all types of explosives.

As a guideline for weapons designers and as an aid to explosives researchers and engineers, the tri-service document and OD44811 describe:

1. Evaluation procedures which must be run (discriminatory tests) before an explosive can be selected for final evaluation in a warhead.

2. Additional background information concerning the explosive which is desirable but not mandatory.

3. Criteria for passing the tests.

This information is presented for primary, booster, and main charge explosives. It is mainly for storable explosives and not for explosives which may be made up and used the same day. Performance tests listed are referenced or presented in the manual, including both those essential and those considered desirable. These are intended to give designers better knowledge as to the type of application best fulfilled by a particular explosive and vice versa.

During the preparation of the documents for interim qualification of primary, booster, and main charge explosives, concern was repeatedly voiced that the explosive formulation made in production would not be exactly the same as that subjected to the qualification tests. Compositions covering the probable range of variance in density, composition, particle size, etc. expected to occur during production should be made and tested; however, the added cost may be prohibitive during interim qualification. It is therefore recommended that any material passing these tests be examined thoroughly at the time of consideration for use in a warhead or other application so that reasonable assurance can be given that the product will be acceptable for the parameters considered. The range considered should cover expected production variability. It is recommended that this variability be further checked as to meeting the requirements of WR-50 by means of designed experiments including expected variable extremes. Some of this information would normally be obtained during development.

It is necessary that several batches of the explosive composition be prepared so that processability by the intended production method is reasonably assured. The composition should be successfully scaled up to at least 100 pounds for main charge explosives, 25 pounds for booster explosives and to a logical production size appropriate for the type of primary explosive, if the method is a noncontinuous process, before it can be considered as having completely satisfied the requirements for interim qualification. Unless otherwise specified in the qualification document, with the evaluation procedure prescribed, at least three batches of approximately the same composition should be tested and should pass the sensitivity and stability tests as required for the type explosive involved before the composition is considered safe. The composition is considered unacceptable if one or more of the batches fail these tests.

It is further expected that any major problems in successful processing by the method of intended production should be worked out so that there are no known outstanding production problems to be solved when interim qualification is granted.

The explosive composition should be sent to the Bureau of Explosives of the Association of American Railroads for appropriate classification (Reference 7) or classified by the appropriately recognized service agency, such as ORD-048 for the Navy on the basis of similar tests.

The fact that an explosive is deemed acceptable for a specific application does not imply that it is acceptable for other ordnance uses. Each new application must be formally approved by the appropriate command.

A booster-type explosive may be allowed as a main charge explosive in some instances. A qualified or interim qualified booster explosive may be used as an interim qualified main charge explosive if a safety analysis of the proposed weapon (or application) has been made and it has been reviewed and approved by ORD-03 or parallel Army or Air Force authority on an individual case basis.

As safety and performance characteristics of explosives may be altered by changes in processing methods or material specifications, deviations from Navy loading procedures and materials specified in the loading documentation require approval of NEDED with concurrence of the Naval Ordnance Systems Command (ORD-03). The Army and the Air Force will require command approval for such changes.

Definitions for purposes of Explosives Qualification

a. Explosives - Chemical compounds or mixtures of compounds which, upon application of a proper stimulus, will detonate or react chemically with extreme rapidity yielding large quantities of gas and heat and accompanied by a high-pressure shock wave. For the purpose of this Instruction, explosives do not include pyrotechnics, propellants, or other energetic materials except when these materials, which may be detonable, are used as the principal energy source for a weapon's destructive effect.

b. Service-Approved Explosives - Explosives which have been approved for service use in a specific service application. These explosives are listed in OP 3613 for Navy approved explosives.

c. Interim Qualified Explosives - Explosives that have not been approved for service use in specific applications but have been approved (by ORD-03 AFATL or Feltman Research Laboratory, Explosive Division) for advanced development leading toward an application.

d. Non-Certified Explosives are compounds or formulations which are neither service approved nor interim qualified. These include explosives still under development and explosivea which, although they may be used commercially or by other services, have not been formally approved or interim qualified.

e. Primary Explosives are sensitive formulations or compounds such as Lead Azide or Lead Styphnate which are used to initiate detonation in high explosives. They are sensitive to heat, impact, or friction and undergo a rapid reation upon initiation. These sensitive explosives are separated from the booster explosive by the interrupter of the fuze, exploder, or safety and arming device.

f. Booster Explosives are compounds or formulations such as tetryl or CH-6 which are used to transmit and augment the detonation reaction (initiated by the primary explosive) with aufficient energy to initiate a stable detonation in the main-charge explosive.

g. Main Charge Explosives are compounds or formulations such as TNT, Composition B, or H-6 which are used as the final charge in any explosive application. These explosives, because of their insensitivity, ordinarily require initiation by a booster explosive.

Qualification Procedures.

a. Primary Explosives. Interim and final qualification shall be in accordance with OD44811. Chapters 1 and 2.

(1) For primary explosives the same information is required for both interim and final qualification. No pass-fail criteria have been assigned for these tests; however, performance ratings of the following tests in accordance with the JT Services Manual (or OD44811) are required:

(a) Thermal Stability

(b) Impact Sensitivity

(c) Electrostatic Sensitivity

(d) Compatibility with materials of construction

Comparison of the values obtained from these tests with values for the in-service explosives lead azide and lead styphnate shall be made.

(2) The following information or tests listed in the manual (References 1 and 2) are desirable. Some of these or other tests may be required by the appropriate command before interim qualification or service approval.

(a) Detonation Velocity

(b) Density

(c) Priming Ability

(d) Dent Output

(e) Dead Pressing Susceptibility

(f) Solubility in Water

(g) Hot Wire Initiability

(h) Stab Initiability

(i) Differential Thermal Analysis

(j) "Cook-Off" Temperature

(k) Friction Sensitivity

(l) Suggested Loading Procedure

b. Booster Explosives. Qualification of booster explosives shall be in accordance with Chapter 3 for interim qualification and Chapter 4, for final qualification (Joint Service Manual or OD 44811).

(1) Performance of the following tests as described in Chapter 3 are mandatory. (Also, performance of selected tests from Chapter 5, section 5.6 for main-charge exploaives may be required for interim qualification)

(a) Samll Scale Gap
(b) Impact Sensitivity
(c) Impact Vulnerability
(d) Vacuum Thermal Stability
(e) Hot Wire Ignition
(f) Thermal Detonability
(g) Electrostatic Sensitivity

(h) Friction Sensitivity

(i) Detonation Velocity

(2) Some of the pass fail criteria listed in the manual for each test are advisory and may be waived on an individual case basis; however, failure to pasa one or more of these tests will generally disqualify an explosive. Comparison of the results of the above mandatory tests with those of at least two booster explosives listed as permissible in MILSTD 1316 shall be made.

(3) Tests for final qualification shall be performed in the same configuration ss will be used in intended service application. The performance of the following tests in accordance with the procedures specified in Chapter 4 is mandatory for obtsining service approval for booster explosives:

(a) Jolt

(b) Jumble

(c) Forty Foot Drop

(d) Trsnsportation Vibrstion

(e) Tacticsl Environment

(f) Temperature and Humidity Cycling

c. Main Charge Explosive. The main charge explosives qualification procedures are deacribed in Chspter 5 for interim qualification and Chapter 6 for finsl qualificstion.

(1) Performance of the following tests as described in Chapter 5 are mandatory for interim qualification. No passfail criteria have been assigned to these tests:

(a) Impact Sensitivity

(b) Lsrge Scale Gap Sensitivity

(c) Friction Senaitivity

(d) Electrostatic Sensitivity

(e) Vacuum Thermal Stability

(f) Growth and Exudation

(g) Self Hesting

(h) Detonation Velocity

(2) A comparison of the data from the above tests shall be made with results obtained with at least two approved main charge

explosives and one booster explosive listed as permissible in MILSTD 1316. If the results of these comparisons indicate that the sensitivity is in the booster range of sensitivity rather than in the main charge range of sensitivity, the mandatory tests listed in Chapter 3, section 5 for booster explosives shall be performed.

(3) The following safety and physical characteristics tests described or referenced in (Reference 1 & 2) are described for background information. Some of these or other tests may be required for either interim or final qualification depending upon the application.

(a) Bullett Impact Sensitivity

(b) SUSAN Sensitivity

(c) Vibration

(d) Drop

(e) Small Scale Gap

(f) High Temperature Exposure

(g) Skid

(h) Compatibility with standard materials

(i) Physical Stability

(j) Physical Properties

(k) Physical Properties at various temperatures

(l) Toxicity

(m) Radiation Effects

(n) Exposure to moisture

(o) Coefficient of thermal expansion

(p) Thermal conductivity

(q) Flexural Strength

(r) Modulus

(s) Hardness

(t) Compressive Strength

(u) Tensile Strength

(v) Impact Resistance

(w) Stiffness

(x) Deformation under load

(y) Bulk Density

(z) Shrinkage on cure

(aa) Flow and injection moldability

(bb) Adiabatic Sensitivity Test

(cc) Thermal Detonability

(dd) Composition Analysis

(ee) Performance

(4) Tests for final qualification shall be performed in the same final configuration as will be used in the service application. For example, a new explosive to be used in a particular Mark and Mod missile warhead, shall undergo final qualification tests in that particular warhead.

(5) Performance of the following tests in accordance with the procedures specified in Chapter 5 of references (1 & 2) or reference (5), is mandatory for obtaining service approval of a main charge explosive. Also, depending on the final application, other tests may be required.

(a) Temperature and Humidity Cycling

(b) Vibration

(c) 40 foot Drop

(d) Bullet impact

(e) Slow Cook-Off

(f) Fast Cook-Off

(6) In cases where the explosive will not be used in a weapon, a test program designed to establish the safety and handling characteristics of the explosive in the proposed configuration shall be prepared and submitted to the appropriate service commands for approval before initiating qualification tests.

(7) The following are tests which, depending on the weapon configuration or service application of the explosive, may be required.

Performance of these tests shall be in accordance with OD 44811 (Reference 1) and WR-50 (Reference 5).

(a) Sympathetic Detonation

(b) Aerodynamic Heating

(c) Safe jettison (aircraft)

(d) Drop on studs

(e) Drop on angle iron

(f) Accidental release (aircraft)

(g) Vibration at low temperature

(h) 40 foot drop at high temperature

(i) Aerial release (Hard target)

(j) Proof pressure firing (guns)

(k) Unseated projectile firing (guns)

(l) Plate penetration

(m) Booster performance

(n) Cratering

(o) Arena

(p) Sled track impact

(q) Fragmentation

(r) Air Blast

(s) Underwater shock and bubble energy

(t) Shaped Charge

(8) The application determines the type of performance most needed whether for metal acceleration, cratering, sir blaat, shaped charge or othar. Table (1) is to be used as s guide to indicate the types of performance evaluation teste which may be required for particulsr intended applications.

d. <u>Additional Evaluation for Service Approvsl (Primary, Booster, and Main Charge)</u>. For service approval of explosives according to reference (1,2) Chapters 2, 4, and 6, the explosives shall hsve been produced successfully. Specifications shall define allowable tolerances for composition, particle size and density variations and methods for determining these values.

6. <u>Action</u>. An interim qualification document may be submitted to the Naval Ordnance Systema Command (ORD-03) or Explosives Division, Picatinny Arsenal or AFATL, Eglin AFB as appropriate, with a request for interim

qualification whenever a new explosive has been tested in accordance with Chapters 1, 3, or 5; When an explosive has been evaluated in accordance with Chapters 2, 4, or 6 and before final weapon approval, a final qualification document containing formal recommendation and including all the supporting data shall be submitted with a request for approval for service use. The cognizant command will then determine whether the explosive has been properly evaluated for safety.

7. Exceptions. For experimental research including synthesis, formulation and processing directed toward interim qualification, explosives not previously qualified may be used alone or in test vehicles for study. Adequate safety measures must be taken, however, to prevent risks to life and equipment.

8. Hazard Classification. Before an explosive is service approved or interim qualified it must have received a hazard classification in accordance with reference (7). The appropriate command can classify explosives on the basis of other tests in reference (1) if some of the tests of reference (7) would constitute unnecessary duplication.

9. Pollution Abatement. The appropriate pollution control methods need to be considered to the satisfaction of the cognizant service command.

10. Packaging, handling, storage and transportation information is required and should be ascertained from the cognizant service.

Performance Evaluation

Suggested performance evaluation methods for explosives depending upon application potential are also contained in the manual. The Table 1 is included as a general guide to correlation of evaluation method with type of ordnance and kill mechanism.

Future Direction

The procedures outlined or referenced in the Joint Services Manual are mainly those that have evolved at government agencies over a long time period. Most of these relate to safety hazards in some way. A review of relevance and a fresh start is suggested for identifying hazards and considering better methods of simulating the hazards as applied to explosives.

Performance Evaluation of Explosives.

Application	Test method										
	Detonation velocity for 8 diameter	Fragment velocity	Gurney constant	Fragment mass distribution	Pressure versus scaled distance	Impulse versus scaled distance	Cylinder expansion	Chapman Jouget pressure	Shaped charge penetration	W. D. (weight for same shock as 1-lb Pentolite)	M. B. E. (Mechanical Bubble Energy)
Bombs	+	+	+	+	+	+	+	+	-	-	-
Shaped charge	+	-	-	-	-	-	+	+	+	-	-
Small caliber shells (to 40mm)	+	+	+	+	+	+	+	+	-	-	-
Large caliber shells	+	+	+	+	+	+	+	+	-	-	-
Torpedoes	+	-	-	-	-	-		-	-	+	+
Depth charge	+	-	-	-	-	-	-	-	-	+	+
Mines	+	-	-	-	-	-	-	-	-	+	+
Blast	+	-	-	-	+	+	-	-	-	-	-
Focussed blast	+	-	-	-	+	+	-	+	-	-	-
Continuous Rod W/H	+	+	+	+	+	+	+	+	-	-	-
Fragmenting W/H	+	+	+	+	+	+	+	+	-	-	-
Bomblets	+	+	+	+	-	-	-	-	-	-	-
Polygon charge	+	+	+	+	+	+	+	+	-	-	-
Destruct system	+	-	-	-	-	-	+	+	-	-	-

+ desirable.
- not needed

Table 1

References

(1) NAVAL ORDNANCE SYSTEMS COMMAND Safety and Performance Tests for Qualification of Explosives NAVORD OD 44811 Vol I, 1 Jan 1972 Naval Weapons Center, China Lake, California (U)

(2) JTCG/ALNNO-WPE Joiot Service Snfety and Performance Manual for Qualification of Explosives for Military Use Naval Weapons Center, China Lake, California 8 Sept 1971 (U) (This edition not issued for general publication)

(3) NAVORD INST 8020.11 **Explosives, Assignment** of Responsibility for [ORD-0332A:RLB 16Feb71

(4) NAVMATINST 8020.1D Naval Explosives Safety Program MAT 046:CAP 12Jan71

(5) WR-50 Naval Weapons Requirements Warhead Safety Tests, Minimum for Air, Surface and Underwater Lauoched Weapons Feb. 1964. (The latest accepted version of WR-50)

(6) U. S. Army Munitions Command "Army Materiel Procedures"

(7) DEPARTMENT of the Army TB700-2,
DEPARTMENT of the Navy NAVORDINST 8020.3
DEPARTMENT of the Air Force TO 11A-1-47
Explosives Hazard Classification Procedures 19May67

For acknowledgements too numerous to include here please see OD 44811.

EFFECT OF PARTICULATE ADDITIVES ON DOUBLE-BASE PROPELLANT SENSITIVITY

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INTRODUCTION

Particulate additives have been used in both gun and solid rocket propellants for many years. In the case of gun propellants, additives have been used as early as the turn of the century. The main functions of the gun propellant additives are to render the propellant flashless and smokeless and to reduce copper deposition in gun barrels.

The use of additives in solid, double-base rocket propellants has been relatively recent. In 1947 it was discovered that lead stearate, used for some time as an extrusion lubricant, contributed to plateau burning (Figure 1) in solid, double-base propellants. From that time there have evolved programs for the research, development, evaluation, and production of improved double-base propellants with additives for burning rate modification.

During development, these improved gun and rocket propellants are subjected to various safety characterization tests to determine explosive classification. The tests are required by NAVORDINST 8020.3, Explosives Hazard Classification Procedures. One of the more important of these tests is the card gap (Figure 2); this test is a measure of the sensitivity of the propellant to detonation from explosive shock.

In this test, the explosive shock from the standard 150 gram tetryl donor is attenuated by acrylic or cellulose acetate cards. The card gap value for a propellant is that thickness of plastic attenuator (measured in cards 0.010" thick) at which the donor shock fails to initiate the sample. By somewhat arbitrary definition, propellants with card gap values exceeding 70 cards are considered Class A explosives while propellants with card gap values of less than 70 cards are considered Class B.

From a safety standpoint it is highly desirable, if not imperative, that improved propellants developed for propulsion systems be in the Class B category.

The validity of the card gap test when applied to finished gun propellant may be questioned since propellant granules are relatively small compared to the card gap test specimen. However, the explosive classification is applicable to processing steps when the material is a consolidated mass. Application of quantity-distance limitations governing processing requires knowledge of the propellant classification.

DISCUSSION

In a general solid propellant improvement and characterization program conducted at NAVORDSTA, Indian Head during 1970 and 1971, it was noted that particulate additives could make a significant change in card gap values and, hence, in classification as an A or B explosives. Therefore, studies were undertaken to characterize various particulate additives for the effect on the solid propellant sensitivity and the card gap test was utilized to measure the effect. The additives were rather common materials not all entirely new to the propellant field.

The studies were conducted on several experimental propellant formulations. Samples were prepared by introducing the various additives in the experimental formulations. The propellant was then subjected to the card gap test.

The effect of the additives on card gap values is shown in Table 1. In this table, the formulations have been grouped according to similarity in composition. Because of the classified nature of the information, samples are indicated by number only and code letters have been used to represent the additives.

Samples with no additives were tested for controls. Card gap test results for the control samples are shown in Figure 3.

The zero card gap value for 12.0%N in the nitrocellulose is shown along with values of 20-25 cards for 12.6%N and 25-30 cards for 13.15%N nitrocellulose. The significance of these values is only as a reference to determine the effects of the additives. Total NC content of the samples was approximately the same and was not considered in the study.

The increase in card gap values resulting from introduction of the additives ranged from 5 to 75 cards. Addition of one percent of B to the Group I formulation increased the card gap value by 75 cards as shown in Figure 4. In combination with additive A at the rate of 0.5 percent of each, the effect of B was to increase gap values by 40 to 50 cards for Group II and III formulations. This increase was above the approximately 25 cards increase resulting from additive A alone as shown in Figure 5.

The additives A and B produced changes of the greatest magnitude for the amount of additive. Additive H also had an exceptional effect as shown by the data for sample 18. Changes for A and B are for approximately 1.0 percent of the additive, however, data are insufficient to precisely define gap change as a function of particulate level for most of the additives.

Throughout the study, the data is consistent in showing an increase in card gap value with increase in a particular additive. Also, the card gap values generally increase with increase in total amount of particulates, all other materials being unchanged. An approximate ranking of the additives in decreasing order of effect on card gap sensitivity is shown in Table 2.

The additives in this study were not soluble in normal double-base propellant systems and appeared as intimately dispersed particles throughout the propellant matrix. The particle size of the additives varied from approximately 5 to 40 microns.

Indications are that the chemical nature of the additives determine, in part, their effect on propellant sensitivity

to shock. This is in addition to any effect resulting from their physical or particulate discontinuity aspect in the propellant matrix. The chemical effect is primarily associated with additives having a high oxygen level. Those additives with high oxygen content increased card gap values to a much greater degree than additives with little or no oxygen. It is believed that these additives act as oxidizers on the surrounding material. It is conjectured that either the ease of the oxidizing reactions or the "hot spots" created at the particles may explain the greater increase in sensitivity for the high oxygen additives.

CONCLUSIONS:

The basic intent of these studies was to characterize particulate additives for their effect on card gap sensitivity. Data is rather limited considering the large number of additives and formulations possible. The effects of plasticizer and additives on the physical properties of the samples and card gap sensitivity were not considered in this analysis. However, the general effect of particulate additives is characterized and guidelines for future propellant development can be based on the following:

1. The introduction of particulate additives in solid double-base propellant systems definitely affects the card gap value.

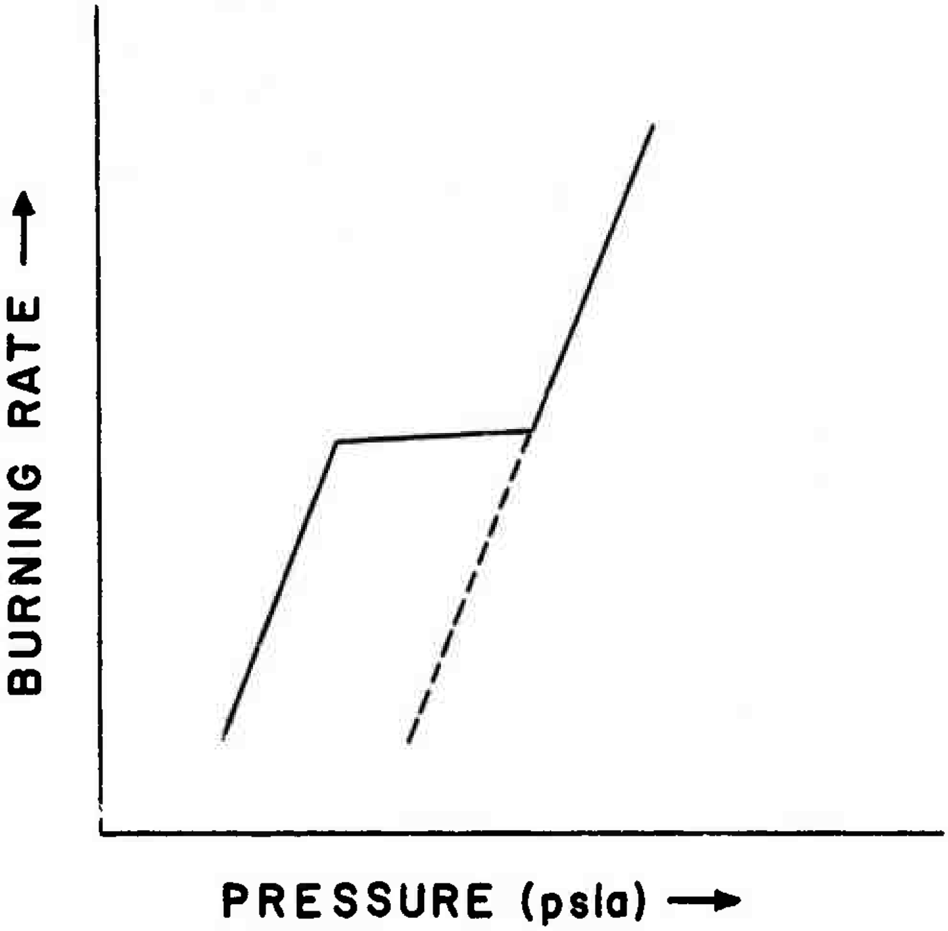
2. In general, an increase in individual or total particulate level will result in an increase in card gap value.

3. Some particulate additives have a much more pronounced effect on card gap value regardless of particulate level.

4. Additives with high oxygen level produce greater changes than those without oxygen. It is believed that when shocked, these additives act as oxidizers on the surrounding material.

5. It should be kept in mind that this data has been

obtained from specific propellant formulations grouped according to similarity in composition. It is quite possible that the introduction of these particulate additives in different systems or in different combinations with other additives could change their relative effect on card gap values.



—— Burning rate curve of propellant w/ ballistic modifier

--- Burning rate curve of propellant w/o ballistic n 'difier

Figure 1 - BURNING RATE vs PRESSURE

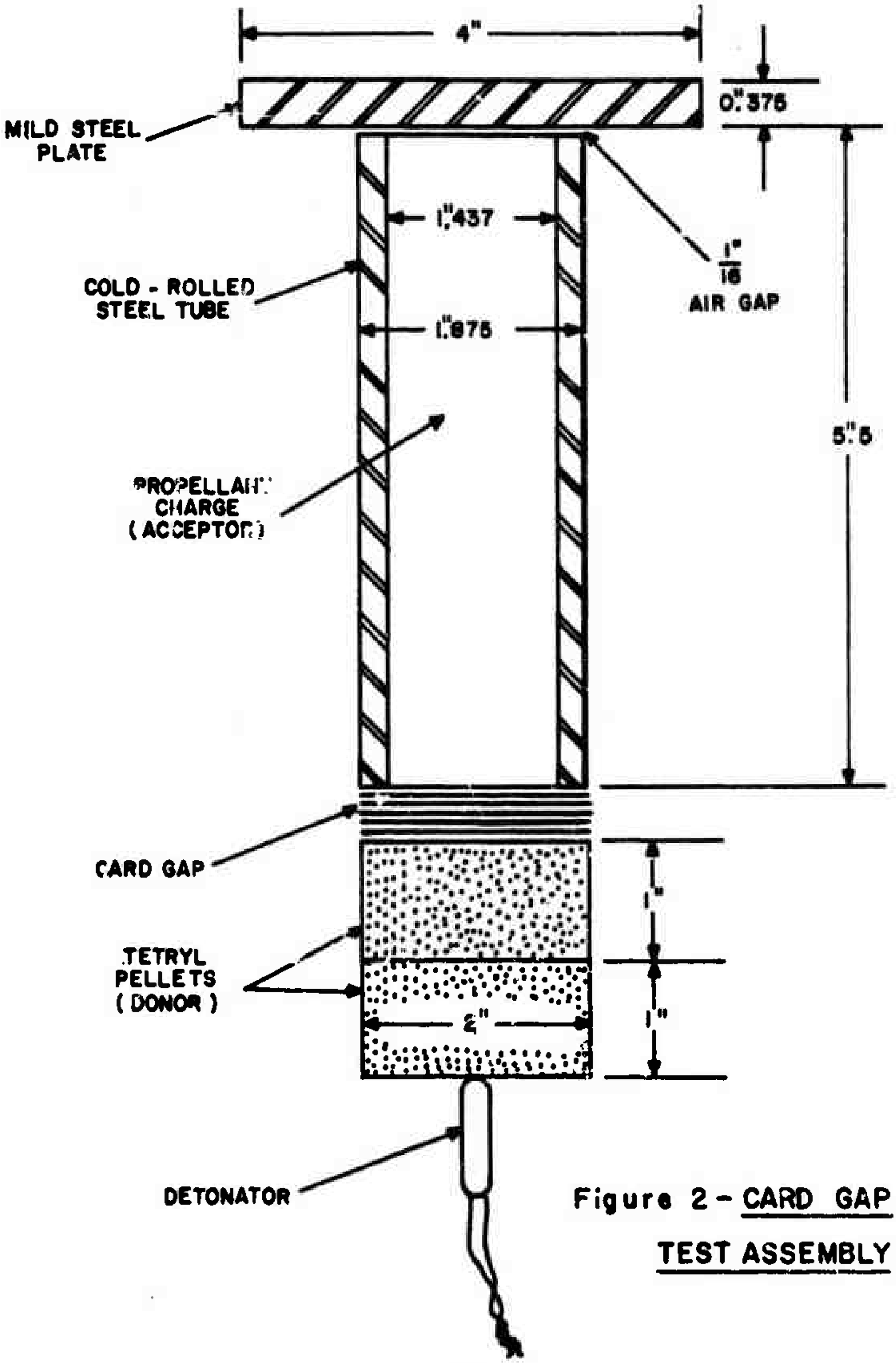


Figure 2 - CARD GAP TEST ASSEMBLY

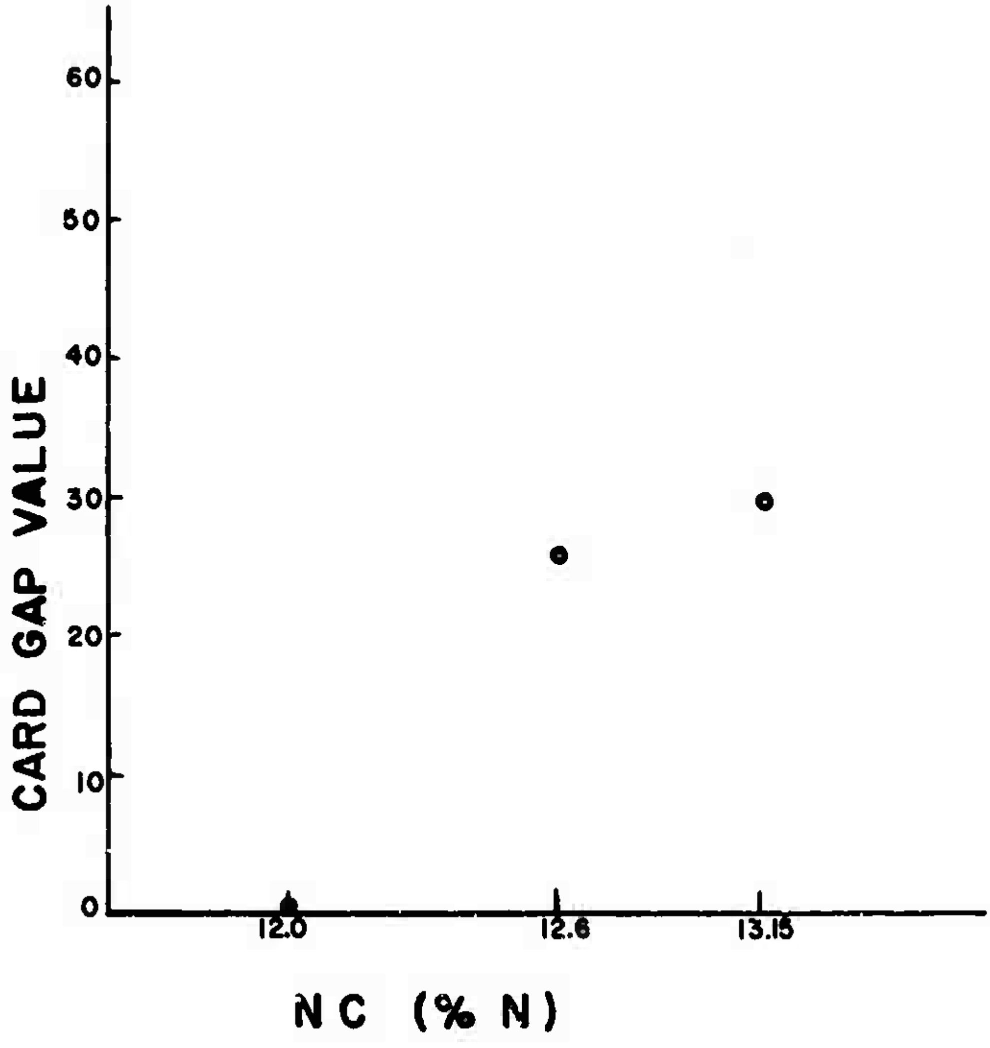
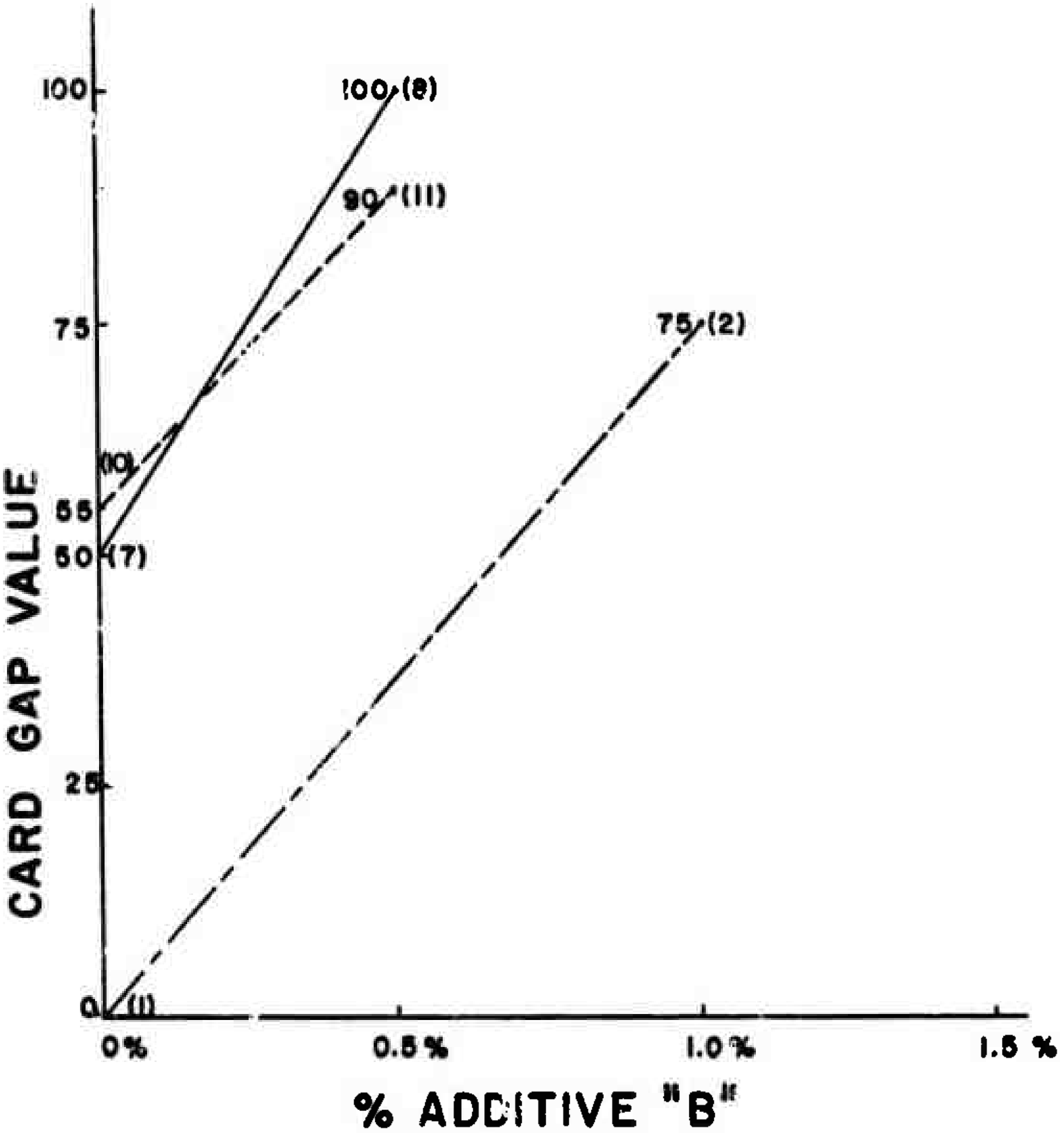


Figure 3 - CARD GAP vs % N in NITROCELLULOSE



(X) — NUMBERS IN PARENTHESIS ARE SAMPLE NUMBERS

Figure 4 – EFFECT of ADDITIVE "B" on CARD GAP VALUES

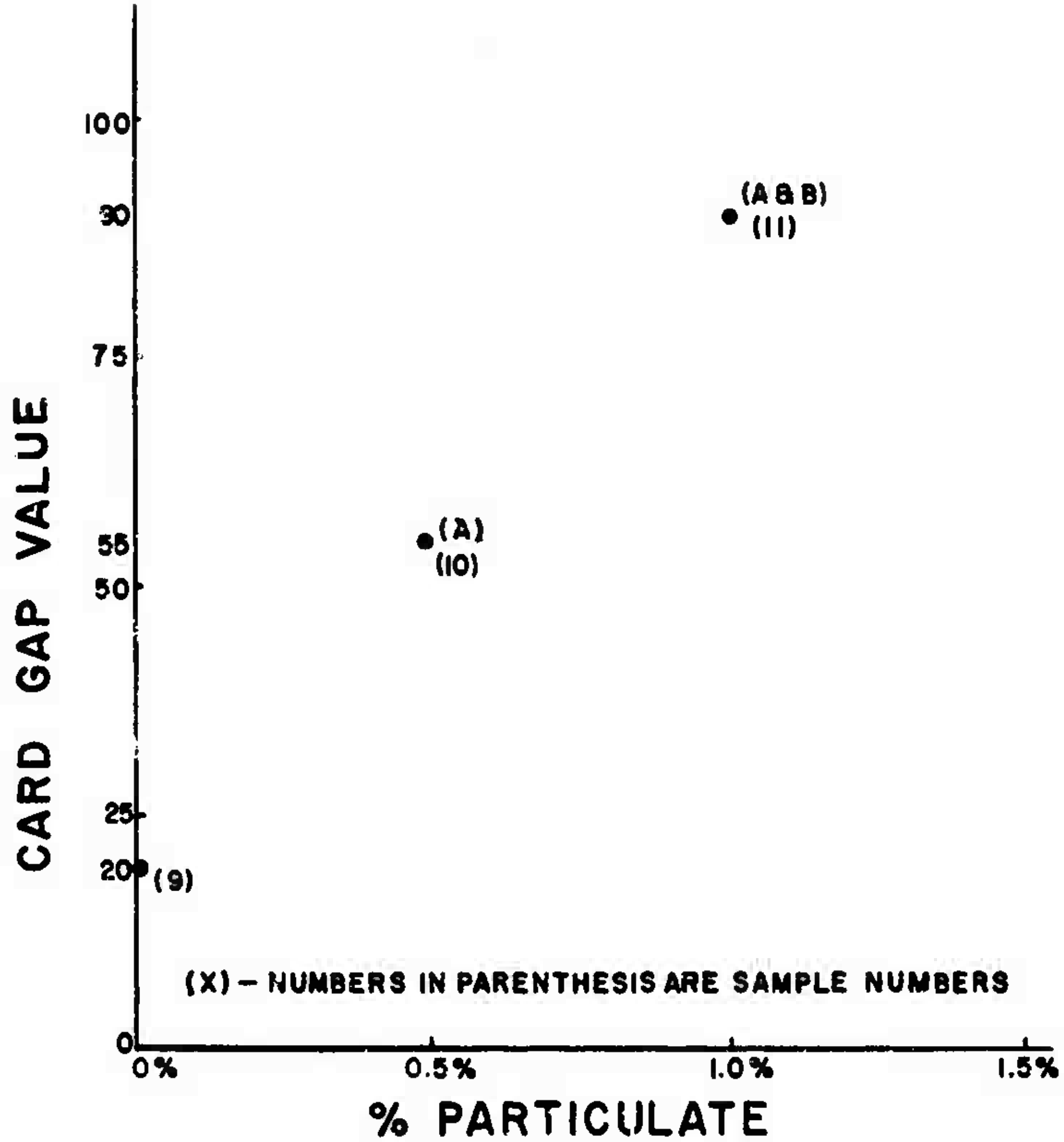
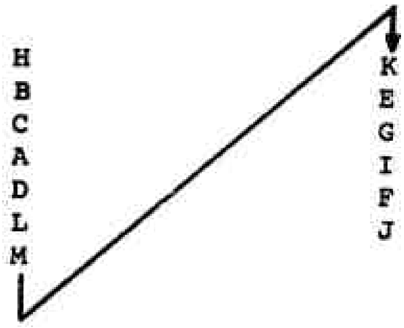


Figure 5 – EFFECTS of COMBINATION of ADDITIVES "A" & "B"

TABLE I
ADDITIVES AND CARD GAP VALUES

GROUP	SAMPLE NUMBER	ADDITIVES	TOTAL ADDITIVES	CARD GAP
I	1	-	0	0
12.0%N	2	B	1.0	75-80
	3	A + B	2.0	64
	4	A + C	2.0	60-65
	5	D + E	2.0	40-45
	6	D	1.0	42-46
II	7	A	0.5	50-55
12.0%N	8	A + B	1.0	100-105
III	9	-	0	20-25
12.6%N	10	A	0.5	55-60
	11	A + B	1.0	90-95
IV	12	-	0	25-30
13.15%N	13	F	1.0	30-35
V	14	E + G + I	4.0	35-40
12.4%N	15	E + G + I	4.5	40-45
	16	E + G + I	5.5	45-50
VI	17	E + G + I + J + K	6.05	55-60
12.6%N				
	18	E + G + H + I + J	7.6	125-130
VII	19	F + I + M	3.0	35-40
12.6%N	20	F + I + L	4.0	55-60
	21	F + I + M	4.5	45-50

Table 2. Rank of Additives in Order of Decreasing Effect on Card Gap Value



EFFECT OF HETEROGENEITY ON THE SENSITIVITY OF HIGH EXPLOSIVE TO SHOCK LOADING

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INTRODUCTION

Shock initiation of solid explosives is greatly influenced by density discontinuities which exist in the explosive as a consequence of casting, pressing or crystallization processes. Bowden and Yoffe[1]* in their pioneering work, demonstrated the effectiveness of density discontinuities (bubbles, voids, inclusions) in producing "hot spots" in shocked or mechanically worked explosives. The high temperatures generated at these sites were shown to cause chemical decomposition under appropriate conditions. The explosive research group at Los Alamos Scientific Lab[2] has made extensive studies on heterogeneous and homogeneous types of initiation; the former is characterized by large defect structure and greater shock sensitivity, the latter, by no defect structure and less shock sensitivity. In the hydrodynamic hot spot[3] concept a shock wave interacts with discontinuities within the explosive causing converging mass flow and increased temperature; the temperature and its duration depend on the nature of the discontinuity, the pressure in the shock wave and hydrodynamic flow conditions around the hot spot. If the hot spot is of sufficient duration and temperature, chemical decomposition occurs and the shock wave can accelerate to a steady state detonation.

The purpose of this effort was to obtain well-defined quantitative data on the effect of density discontinuities upon the initiation process. These data could then be analyzed in order to assess the validity of some of the concepts used in modeling the initiation of detonation in high explosives. Several of these concepts and their impact were discussed previously by one of the authors[4].

Inclusions of controlled numbers and sizes were added to the homogeneous explosive, nitromethane, in order to simulate a heterogeneous explosive of known defect structure. The inclusion size, material and amount were varied in order to study their effects on shock sensitivity.

* *References are listed on page 857.*

EXPERIMENTAL DETAILS

A. Mixture Preparation

Inclusions were added to the nitromethane on a per cent by volume basis; i.e. the volume of inclusions in the mixture was a predetermined percentage of the total mixture volume. A total mixture volume of 300 ml was selected as being a convenient amount for blending. Since the density of the inclusion material was known, an amount corresponding to the desired volume was weighed. This was then slowly poured into the nitromethane, stirring the mixture, in order to wet the powder and minimize clumping. Next, a gelling agent, Cab-O-Sil*, was added to the mixture in order to produce a viscous mixture and in which the inclusion particles settled very slowly. The amount of gelling agent added depended on the size and amount of inclusions in the mixture; in general, the smaller the size, and the greater the amount of inclusions, the less the gelling agent that was required to produce a mixture with the properties described above. The weight of gelling agent added ranged from 3.0 to 10.0 grams for a 300 ml mixture of inclusions and nitromethane. The volume of the gelling agent was not included in the total mixture volume.

In order to disperse the gelling agent in the mixture an ordinary household blender was used at low speed for 30 seconds. The blending operation was done under a vacuum of approximately one Torr in order to prevent the formation of air bubbles in the viscous mixture. Microscopic examination confirmed the absence of air bubbles. The blending operation was done remotely under a bell jar in a blast chamber since the sensitivity of the explosive mixture was not known.

B. Materials Used

The mixtures were made from the appropriate combination of the following ingredients:

Nitromethane (Commercial grade) dens.=1.125 g/cm^3

* Cab-O-Sil is a submicroscopic, fire-dry fumed silica made by Cabot Corp.

Cab-O-Sil (grade M-5)	dens.=2.2	g/cm^3
Aluminum Oxide (abrasive powder)	dens.=3.98	g/cm^3
Copper (Spherical, grade 1002)	dens.=8.90	g/cm^3
Glass (soda-lime-silica composition, spherical)	dens.=2.45	g/cm^3

The range of inclusion size and concentration is shown below:

INCLUSION MATERIAL	RANGE OF INCLUSION SIZE (microns)	RANGE OF INCLUSION CONCENTRATION (% volume)
Aluminum Oxide	0.5 - 80	0.16 - 20
Copper	49 - 97	5
Glass	25 - 200	2.5 - 20

When the blending operation was completed the mixture was removed from the bell jar and poured into a beaker. The consistency of the mixture was similar to that of apple sauce for glass or copper inclusions and similar to a thinned paint for aluminum oxide inclusions.

C. Test Arrangement

The blended mixture was carefully poured into the wedge-shaped container shown in Figure 1. The container was made of Plexiglas but the insert was made of Homalite, a plastic impervious to Nitromethane; the underside of the insert was aluminized in an evaporative coater. A four inch diameter plane wave lens and buffer plate produced a shock wave which was simultaneous within forty nanoseconds over the area of the experiment, the central two inches of the buffer plate. This shock propagated into the mixture and its progress was recorded by a rotating-mirror streak camera, writing at 8.8 mm/μsec. The camera slit was focused on the slant face of the wedge. Shock arrival at the insert was detected as a change in reflectivity of the aluminized surface; an "argon bomb" light source illuminated the event.

D. Data Reduction

Streak camera records provided distance and time coordinates of the shock propagation in the mixture. From these data, shock velocities were computed as the quotient of incremental differences in distances and times.

The density of the mixture was calculated from the known density and amount of constituents.

An impedance matching technique was used to determine the initial shock pressure in various mixtures and to determine a Hugoniot curve, shown in Figure 2, for two mixtures (10% glass, 10% aluminum oxide). This technique requires knowledge of the density and initial shock velocity in the mixture and the shock pressure in the buffer plate adjacent to the mixture. The shock pressure in the buffer plate was determined in an auxiliary experiment on a similar explosive-buffer combination using a material (Plexiglas) of known Hugoniot and applying the impedance matching technique. For the low pressure Plexiglas Hugoniot Barker's[5] data were used; a least squares fit was made to his fifteen highest pressure points. This gave,

$$U = 2.987 + .825\, u_p, \quad 3.0 \leq U \leq 3.7.$$

For higher pressures, Hauver's[6] Plexiglas Hugoniot was used,

$$U = 2.68 + 1.61\, u_p.$$

The inclusion size reported is that supplied by the manufacturer. The total surface area, K, of inclusions for a given mixture is proportional to the number present and the square of the inclusion diameter,

$$K \sim n\, d^2 \sim \frac{\%\text{vol.}}{d^3}\, d^2 = \frac{\%\text{vol.}}{d}$$

The base angle of the wedge was kept small enough so that rarefactions

originating near the lateral boundaries of the experiment could have no effect on the shock wave being observed. The base angle was measured on each shot and held close to 3S°.

Since the thickening agent, itself, consists of chain-like configurations of very fine (0.012 micron) particles of silicon dioxide, preliminary testing was done to see whether these fine particles would induce explosive reaction and consequent acceleration of the shock front. Nine grams of Cab-O-Sil were added to 300 ml of nitromethane and blended as described previously. The thickened mixture was poured into a wedge shape atop a buffer plate and a 60 kilobar shock was sent into it. Streak camera observation of the shock wave showed that it failed to detonate and its velocity decayed indicating that no appreciable reaction was taking place. A similar firing, using straight nitromethane, didn't detonate and the shock velocity decayed. Both firings are presented in Figure 3. The slight difference in velocity between the two curves can be ascribed to variations in donor pressure. There, within the precision of measurement, the Cab-O-Sil had no effect upon the shock properties of the nitromethane.

RESULTS

The data in this section can conveniently be considered in terms of the inclusion material, size, number, total surface area and optimum inclusion size.

A. Effect of Inclusion Size

Figure 4 shows the shock build up curves for three sizes of glass bead inclusions. Shock velocity is plotted against the distance the shock has propagated into the mixture. The initial pressure is approximately sixty kilobars. As can be seen in the figure, for constant inclusion

volume, the smaller sizes promote more rapid build up. The shock velocity increases continuously at first and then abruptly attains a velocity beyond the normal detonation velocity. This overdriven condition gradually settles down to a steady velocity characteristic of the mixture. The distance at which the abrupt transition to detonation occurs (the distance to detonation) is a measure of the sensitivity of the mixture. The shorter the distance to detonation, the more sensitive the mixture. All curves are eye fits to the data.

B. Effect of Inclusion Number

Figure 5 shows shock build up curves for glass bead inclusions of constant size. The number of beads was varied as indicated in the figure. The shock velocity accelerates continuously at first, becomes overdriven and settles down to steady detonation rate. The curves illustrate that for constant inclusion size, greater numbers produce a more sensitive mixture.

C. Effect of Inclusion Material

Figure 6 shows shock build up curves for aluminum oxide inclusions of several different sizes. In particular, the twenty five micron aluminum oxide curve can be compared to the glass bead curve of the same size and concentration in Figure 4. Aluminum oxide inclusions promote a more rapid build up as evidenced by the shorter distance to detonation. The shock wave accelerates continuously over the first part of the build up curve and then very rapidly reaches detonation velocity with little or no overdrive apparent.

The effects of inclusion size, number and material are summarized in Figure 7 where distance to detonation is plotted against total inclusion volume.

D. Total Surface Area

Figure 8 is a plot of K (proportional to the total surface area of the inclusion) against the distance to detonation. Aluminum oxide and copper gave similar results. The curves suggest the importance of surface area effects in explosive sensitivity.

E. Optimum Inclusion Size

Figure 9 is a plot of inclusion diameter vs. distance to detonation for copper, aluminum oxide, and glass inclusions at a constant 5% inclusion volume. The aluminum oxide curve suggests the existence of an optimum inclusion size; i.e. a size which, for given total inclusion volume, will produce the most shock sensitive mixture.

DISCUSSION

In Ref. 4, a simplistic model for the shock initiation of detonation in heterogeneous explosives was developed. The assumption of single curve buildup, temperature dependent reaction rates, a void number density proportional to the total void volume, and a critical ignition condition led to an interpretation of the buildup process consistent with data from the literature on tetryl. In this effort, essentially the same assumptions are used, and the equations are rederived, as Ref 4 contained some errors.

SINGLE CURVE BUILDUP

Figure 10 shows that, within the precision of the data, single buildup occurs. Thus, it may be assumed that the buildup process is history independent, and the acceleration of the shock wave during the buildup process is completely determined by the instantaneous values of the state variables at the shock front. Prescription of a single shock variable and initial conditions determines the values of all other variables and their time derivatives in the problem of the reaction supported, planar, semi-infinite, non-steady shock, which these experiments closely approximate. All rate processes involved in the buildup to detonation are therefore determined by specification of one shock variable. This may be expressed mathematically as

$$\frac{d\Psi}{dt} = F(X, a_i) \qquad (1)$$

where Ψ is any state, flow, or rate variable, e.g., P, U, or $\dot{Q}$; X is any state or flow variable used to define the shock, and a_i are initial parameters.

TEMPERATURE DEPENDENT REACTION RATES

In most combustion type reactions, the influence of temperature on the heat release rate has a very strong exponential character. Conversely, the temperature depends upon the other variables in the reaction rate equation only logarithmically. In the heterogeneous initiation process, this strong temperature dependence is compounded by the fact that, at hotspots, temperatures are generated far in excess of those in the bulk phase. Furthermore, the greater be the time to reaction at a hotspot, the greater the distance of the hotspot from the front. Hence, its contribution to the buildup, due to rarefaction effects, is less. Thus, a critical hotspot temperature is assumed. It can easily be shown that the peak temperature of the hotspot is independent of hotspot size. (This is not true of either the spatial or temporal distribution of the temperature, each of which is a function of inclusion size). The temperature at a hotspot or in the bulk phase may be related to the internal energy density through the equation of state of the explosive. In the following, the internal energy density shall be used in place of the temperature as the independent variable, and the critical hotspot temperature will be replaced by a critical hotspot internal energy density.

THE BUILDUP CURVE

One may now use Equation (1) to investigate the buildup process. The internal energy density at the hotspot, E, is chosen as the independent variable and, $\dot{Q}$, the total areal heat release rate, is chosen as the dependent variable. In keeping with grain burning models, the heat release rate at a site is taken to be proportional to the surface area of the site. One thus obtains an expression for the total area heat release rate in terms of the sites, viz:

$$\dot{Q} = s\dot{q} \tag{2}$$

where $\dot{q}$ is the heat release rate per unit site area and s is the total surface area of the sites. Equation (1) becomes

$$\frac{d\dot{q}}{dt} = F(E) \tag{3}$$

or

$$\frac{d\dot{Q}}{dt} = sF(E) \tag{4}$$

which describes the total area heat release rate as a function of the total site surface area and the site internal energy density. In Reference 4, loss terms were accounted for by transforming variables to a reduced energy density representation:

$$F(E) \rightarrow F(\xi) \qquad (5)$$

where $\xi = \dfrac{E-E_c}{E_{cj}-E_c}$ varies from zero at the critical energy density, $E = E_c$, to unity at the Chapman Jouguet point, $E = E_{cj}$. This was necessary, as the Hugoniot for Tetryl was shown to be a function of loading density. However, Figure 2 shows that, for nitromethane, addition of up to 10%v inclusions does not appreciably affect the Hugoniot. Here, therefore, the original representation is retained, and Equation 3 is integrated directly to yield

$$\int_{E_o}^{E_{cj}} \frac{d\dot{Q}}{dE} \frac{dE}{F(E)} = st \qquad (6)$$

where the integration over t has been performed.* The integration of the left hand side cannot be performed, since the functional dependence has not been specified. However, Equation (4) is useful in several ways. First, it implies that, for a constant hotspot energy density, a plot of total surface area versus time to detonation should be a hyperbola. This is shown in Figure 11. Alternatively, a plot of log s versus log t should, for constant E, be linear. Figure 12 shows this relationship for Al_2O_3 and glass inclusions. It is important to note that the two curves have the same slope, indicating that the only difference in effects of the two materials is to produce different hotspot energies for the same input shock. This can be checked fairly easily.

* The analogous equation in Reference 4 should read

$$\frac{1}{N^{1/3}} \int_{\xi=0}^{\xi} \frac{d\dot{Q}}{dq} \frac{d\xi}{F(\xi)} = (1-\Lambda)^{2/3}\, t,$$

From Figure 13, one has, at $S=S_o$

$$\frac{dt}{dE} = -a(s)t \tag{7}$$

or

$$t = g(s)e^{-a(s)E} \tag{8}$$

It should be noted that equations (7) and (8) are purely empirical and have no theoretical foundation. In fact, (8) can be approximately true over only a limited range of t and E, as it doesn't have the correct limiting behavior. However, it fits the data!

From Equation (6), one has that

$$ts = C(E) \tag{9}$$

Elimination of t from Equation (8) leads to

$$C(E)e^{a(s)E} = g(s)s \ .$$

Since the right hand side of Equation (10) is a function of s only, the left hand side must be independent of E.

Thus,

$$\frac{dC(E)}{dE} e^{a(s)E} + a(s)C(E)e^{a(s)E} = 0 \tag{11}$$

or

$$C(E) = be^{-a(s)E} \tag{12}$$

where b is a constant.

By similar reasoning, $a(s) = a$, where a is a constant,

and $$g(s) = b/s \tag{13}$$

Thus, one has that

$$st = be^{-aE} \tag{12}$$

where b and a are independent of s, t, and E. Values for b and a were obtained from Figure 13. Equation 12 is shown schematically in Figure 14.

HOTSPOT INTERNAL ENERGY DENSITY

An approximate value of the internal energy density at a hotspot may be obtained graphically by using the Hugoniot relations for nitromethane Al_2O_3, and glass in the P-Up plane to determine the values of the variables behind the shock reflected from the appropriate inclusion, as functions of initial shock conditions. This approach assumes single shock reflection from a planar interface and neglects effects caused by the finite size of the inclusion.

It can be shown easily that the internal energy density differs from the kinetic energy density by the shaded area in Figure 15. Thus, from the Hugoniot relations, the hotspot internal energy density is given by

$$E = \frac{(P_1+P_o)}{2}(V_o-V_1) + \frac{(P_2+P_1)(V_1-V_2)}{2} \tag{13}$$

and

$$E_K = \frac{(P_1-P_o)(V_o-V_1)}{2} + \frac{(P_2-P_1)(V_1-V_2)}{2} \tag{14}$$

where E_K is the hotspot kinetic energy density.

Furthermore,

$$2E_K = (U_1)^2 + (U_2-U_1)^2 \tag{15}$$

Neglecting P_o in Equations (13), (14) and subtracting (14) from (13), one has

$$E-E_K = P_1(V_1-V_2) \qquad (16)$$

so that

$$E = \frac{(u_1)^2}{2} + \frac{(u_2-u_1)^2}{2} + P_1(V_1-V_2) \qquad (17)$$

Equation (17), in conjunction with graphs of the P-U Hugoniots for nitromethane, Al_2O_3, and glass, was used to compute values of E for various initial shock conditions. Equation (12) was rewritten in the form

$$s \cdot \frac{t}{b} e^{aE} = 1 \qquad (12^1)$$

A plot of s <u>versus</u> $\frac{t}{b} e^{aE}$ for both the Al_2O_3 data and the glass data should lead to a single hyperbola. This is shown in Figure 16.

CONCLUSIONS

The results of this study clearly show that the time to detonation, for a given strength input shock, is inversely proportional to the total surface area of the inclusions, as long as the inclusions are above a certain minimum size. For a given volume concentration of inclusions, there is an optimum inclusion size, i.e., a size which gives the most sensitive explosive.

The nature of inclusion material affects the buildup time. For a given total surface area, aluminum oxide powder produced more efficient hotspots than the glass beads did. It has been shown that it is consistent to interpret the efficiency in terms of the internal energy density generated behind the shock reflected from the inclusions. Therefore, the most important result of this study is that, once the internal energy density at the hotspot is fixed, and the total surface area of inclusions is specified, the time to detonation is determined, independent of the number of hotspots, the

strength of the initial shock, or the total inclusion volume percentage.

Several areas of this study require additional work. In particular, sufficient data should be obtained to clearly define a critical energy density for ignition. Secondly, measurements should be extended to short duration pulses and divergent geometries. The greatest theoretical weakness is in the inability to predict or explain the lnt-E functional dependence of any particular buildup curve.

ACKNOWLEDGMENTS

The authors are indebted to many members of the BRL staff for their enthusiasm and helpful assistance.

LIST OF FIGURES

LIST OF SYMBOLS

P_o	Pressure in unshocked material
P_1	Pressure behind incident shock
P_2	Pressure behind reflected shock
V_o	Specific volume of unshocked material
V_1	Specific volume hehind incident shock
V_2	Specific volume behind reflected shock
u_1	Particle velocity behind incident shock (measured in lab system of coordinates)
u_2	Particle velocity behind reflected shock (measured in laboratory coordinate system)
U	Velocity of incident shock
E	Hotspot internal energy density
E_K	Hotspot kinetic energy density
a,b,	Constants of integration, independent of s,t, E
$s=\frac{nd^2}{2}$	Total surface area of inclusions
n	Number of inclusions/cc nitromethane mixture
d	Diameter of inclusions
t	Time to detonation
$\dot{q}$	Heat release rate per unit site area
$\dot{Q}$	Total area heat release rate

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6. M. Van Thiel et al, eds., Compendium of Shock Wave Data, Vol. II, UCRL 50108.

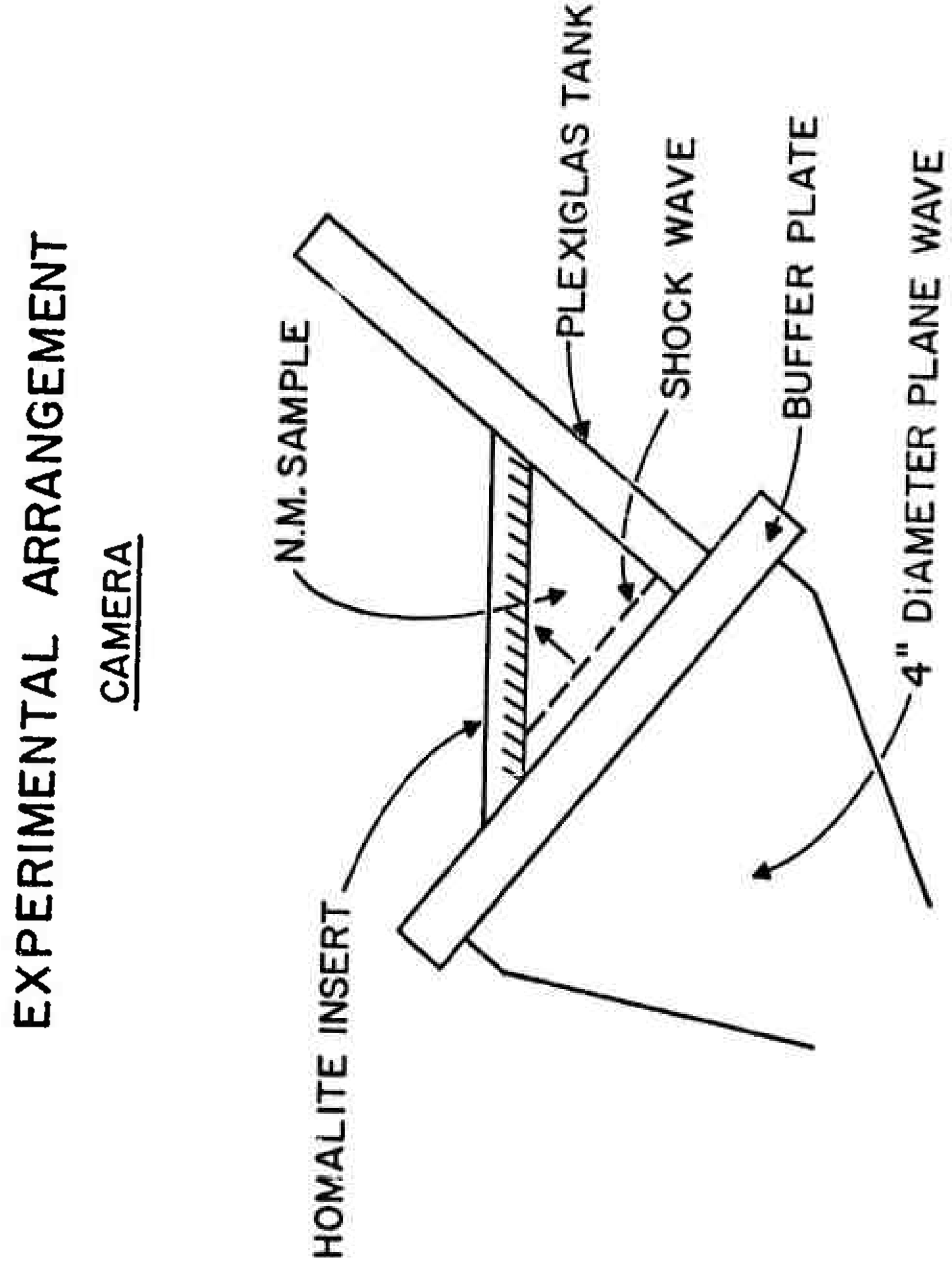
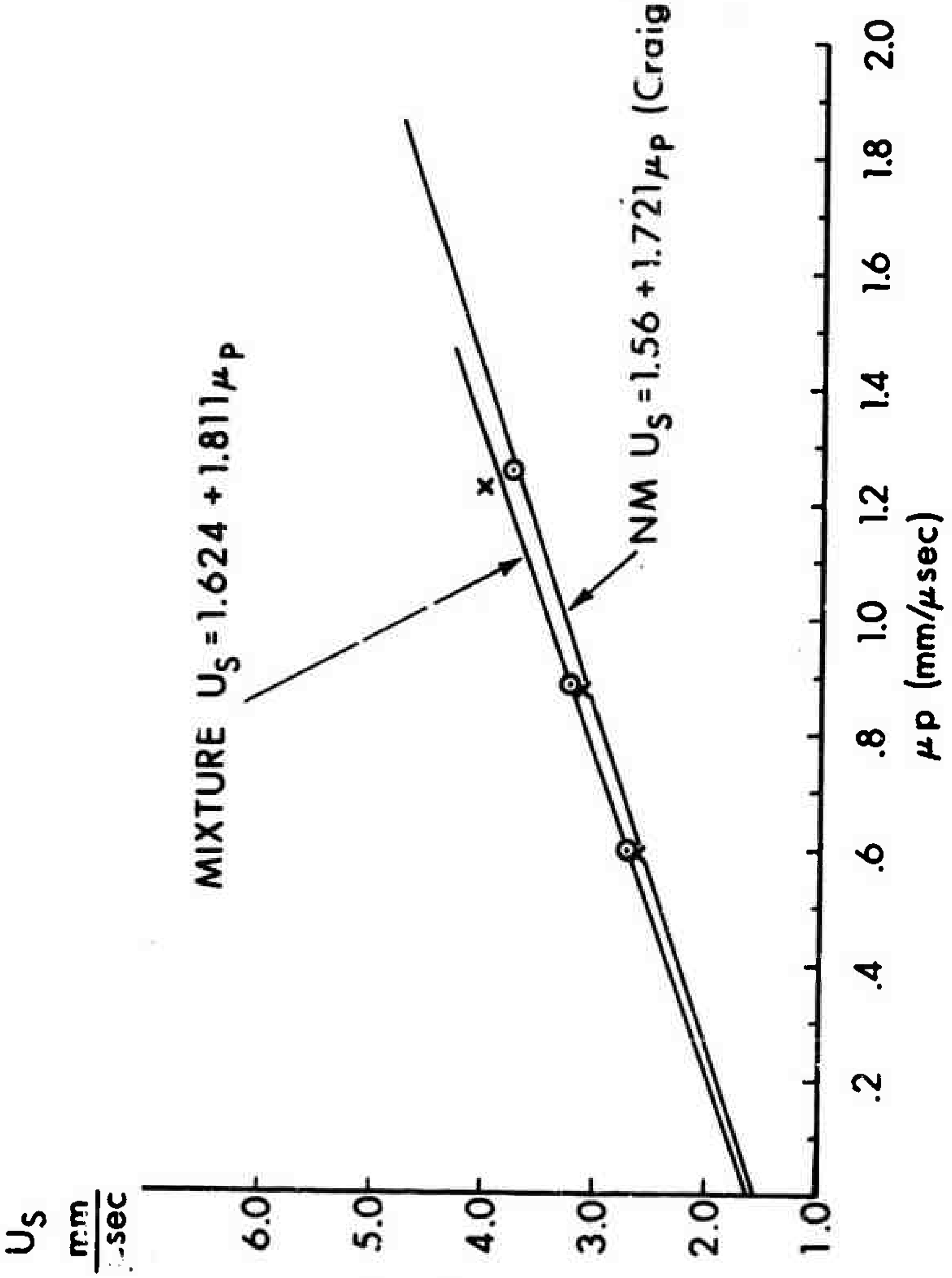

EXPERIMENTAL ARRANGEMENT
CAMERA
N.M. SAMPLE
PLEXIGLAS TANK
SHOCK WAVE
BUFFER PLATE
4" DIAMETER PLANE WAVE
HOMALITE INSERT

Figure 1



MIXTURE $U_S = 1.624 + 1.811\mu_P$
NM $U_S = 1.56 + 1.721\mu_P$ (Craig)
μp (mm/μsec)
U_S
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
1.0
2.0
3.0
4.0
5.0
6.0

Figure 2

COMPARISON OF SHOCK VELOCITY IN NM WITH THAT IN NM CONTAINING GELLING AGENT

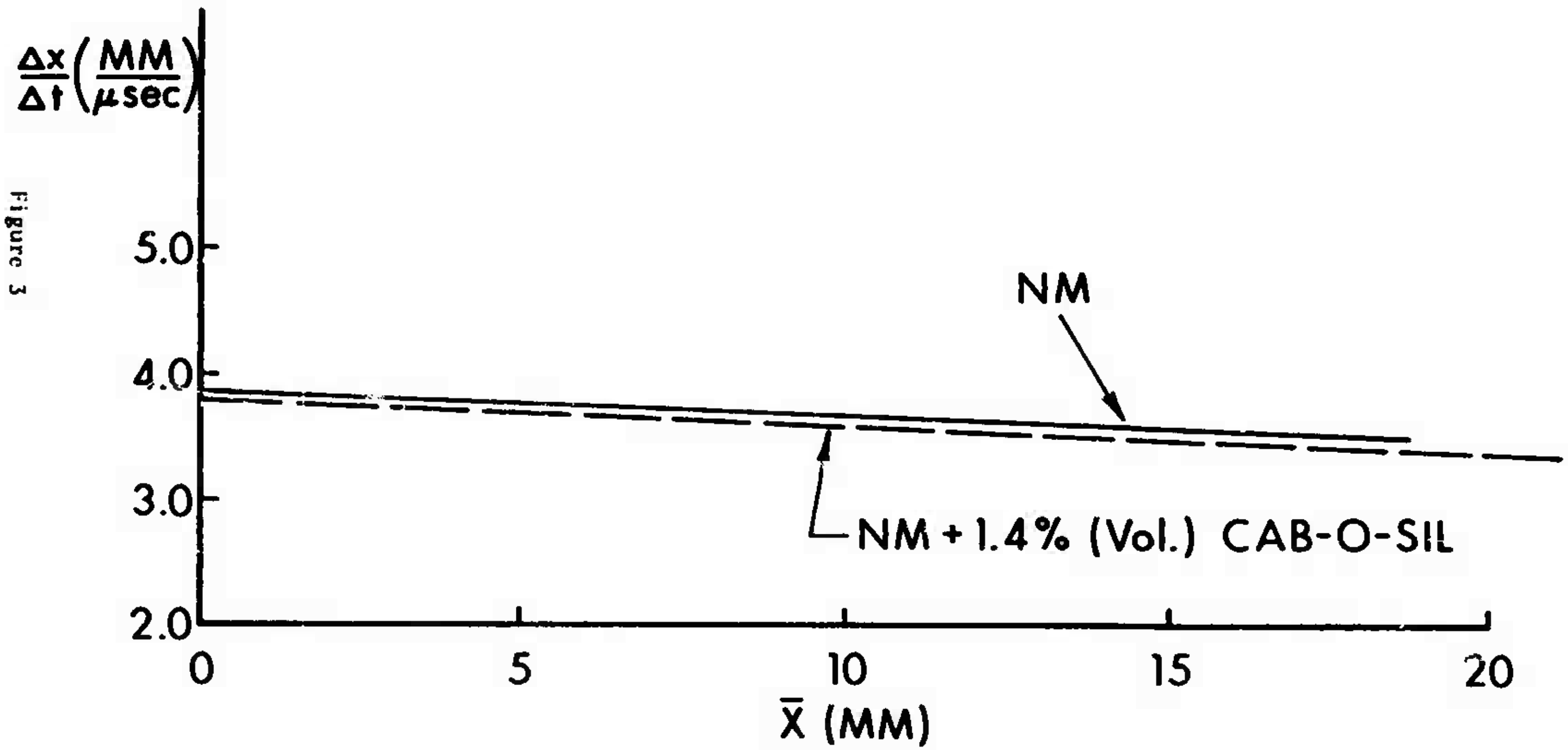
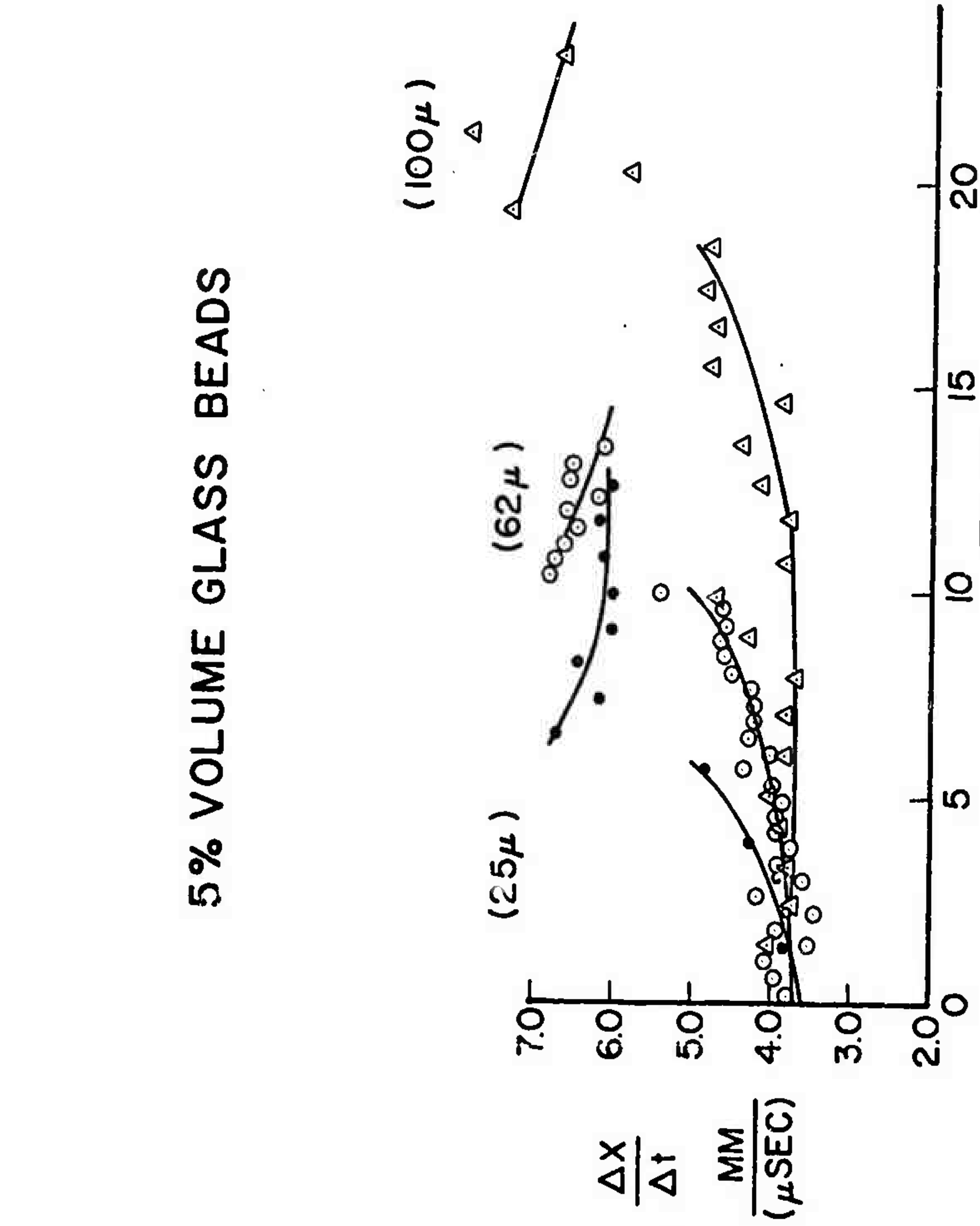
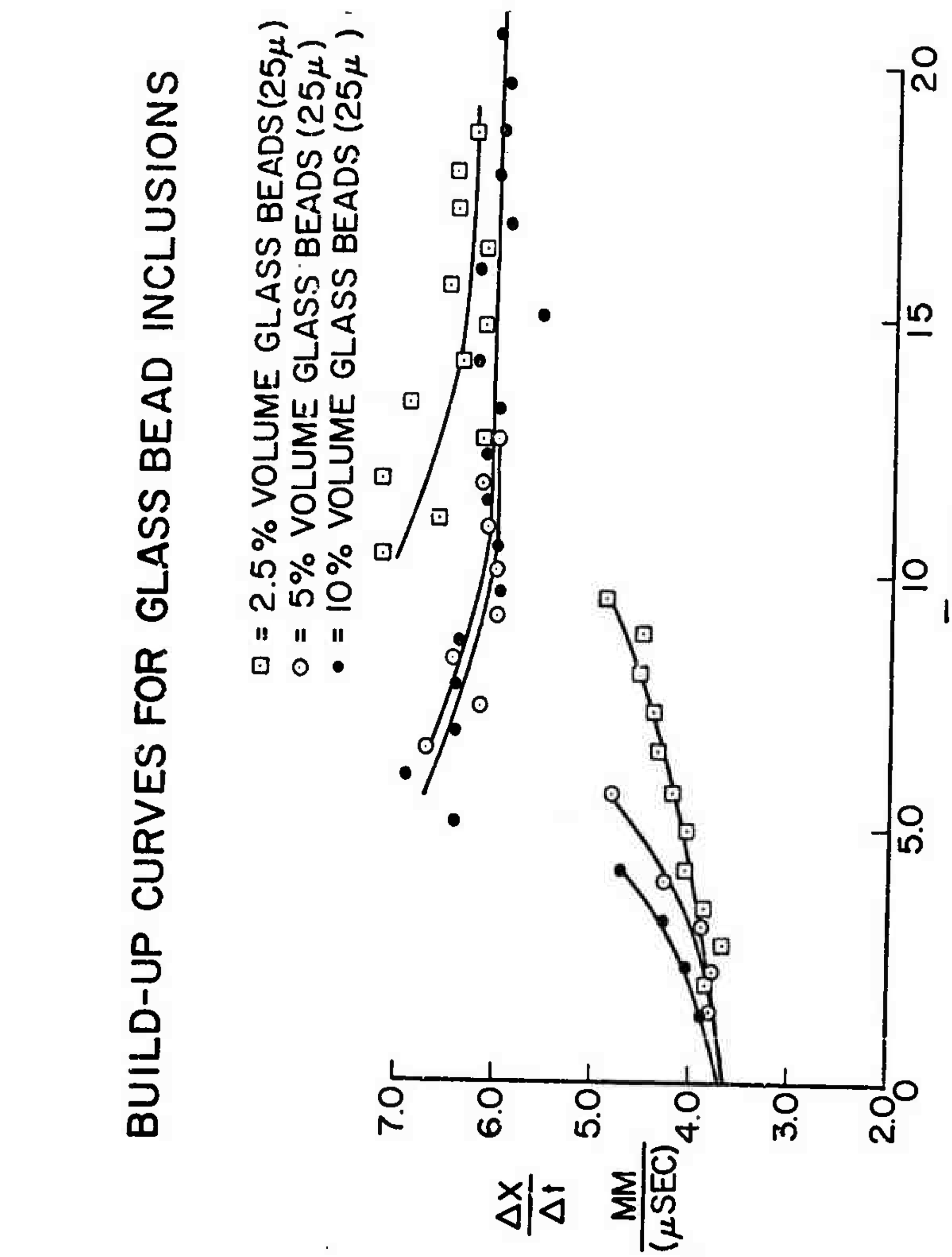


Figure 3



5% VOLUME GLASS BEADS
(25μ)
(62μ)
(100μ)
$\frac{\Delta X}{\Delta t}$ $\frac{MM}{(\mu SEC)}$
7.0
6.0
5.0
4.0
3.0
2.0
0
5
10
15
20
$\overline{X}$ (MM)

Figure 4



BUILD-UP CURVES FOR GLASS BEAD INCLUSIONS
□ = 2.5 % VOLUME GLASS BEADS (25μ)
⊙ = 5% VOLUME GLASS BEADS (25μ)
• = 10% VOLUME GLASS BEADS (25μ)
$\frac{\Delta X}{\Delta t}$ $\frac{MM}{(\mu SEC)}$
7.0
6.0
5.0
4.0
3.0
2.0
0
5.0
10
15
20
$\overline{X}$ (MM)

Figure 5

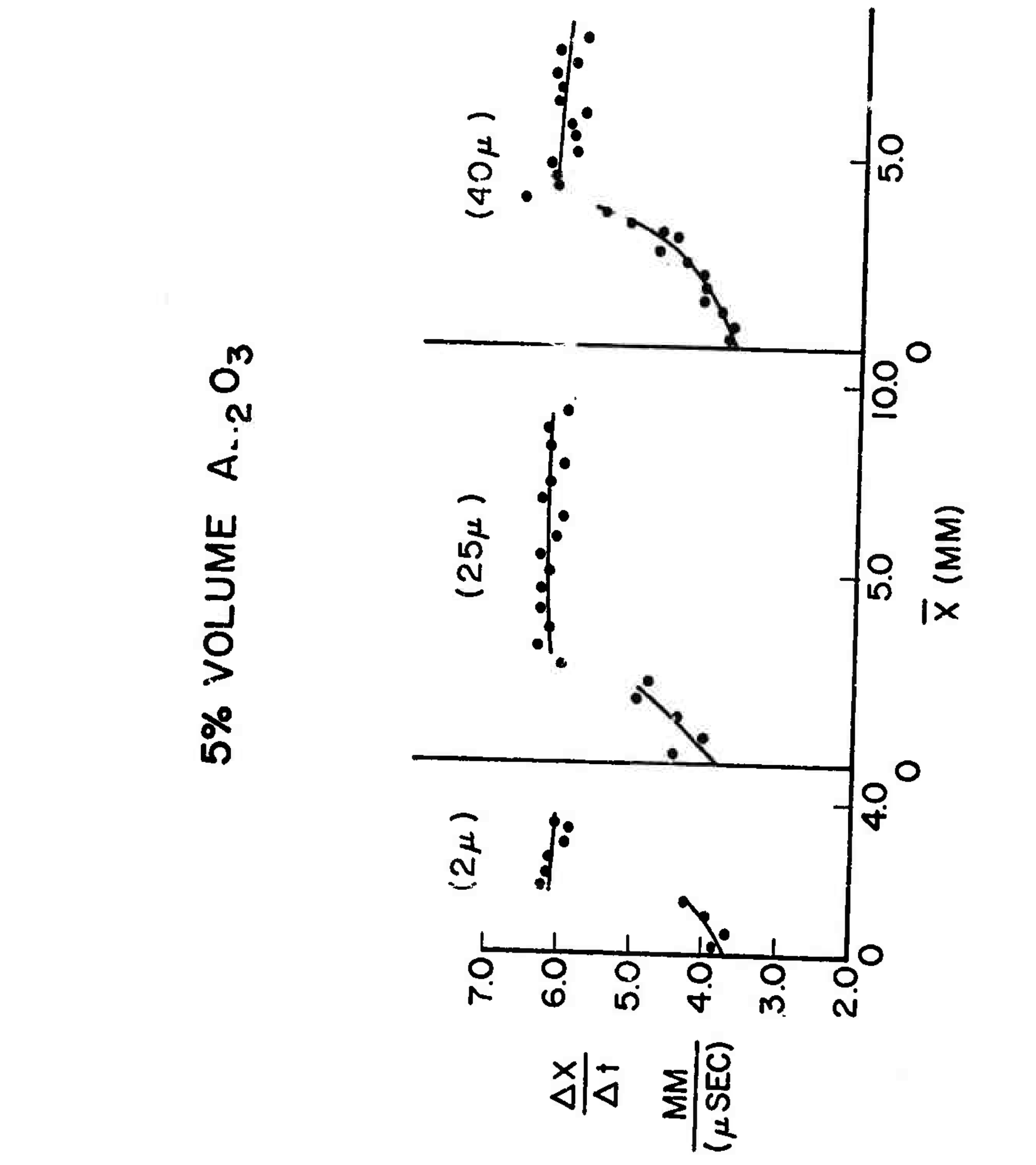
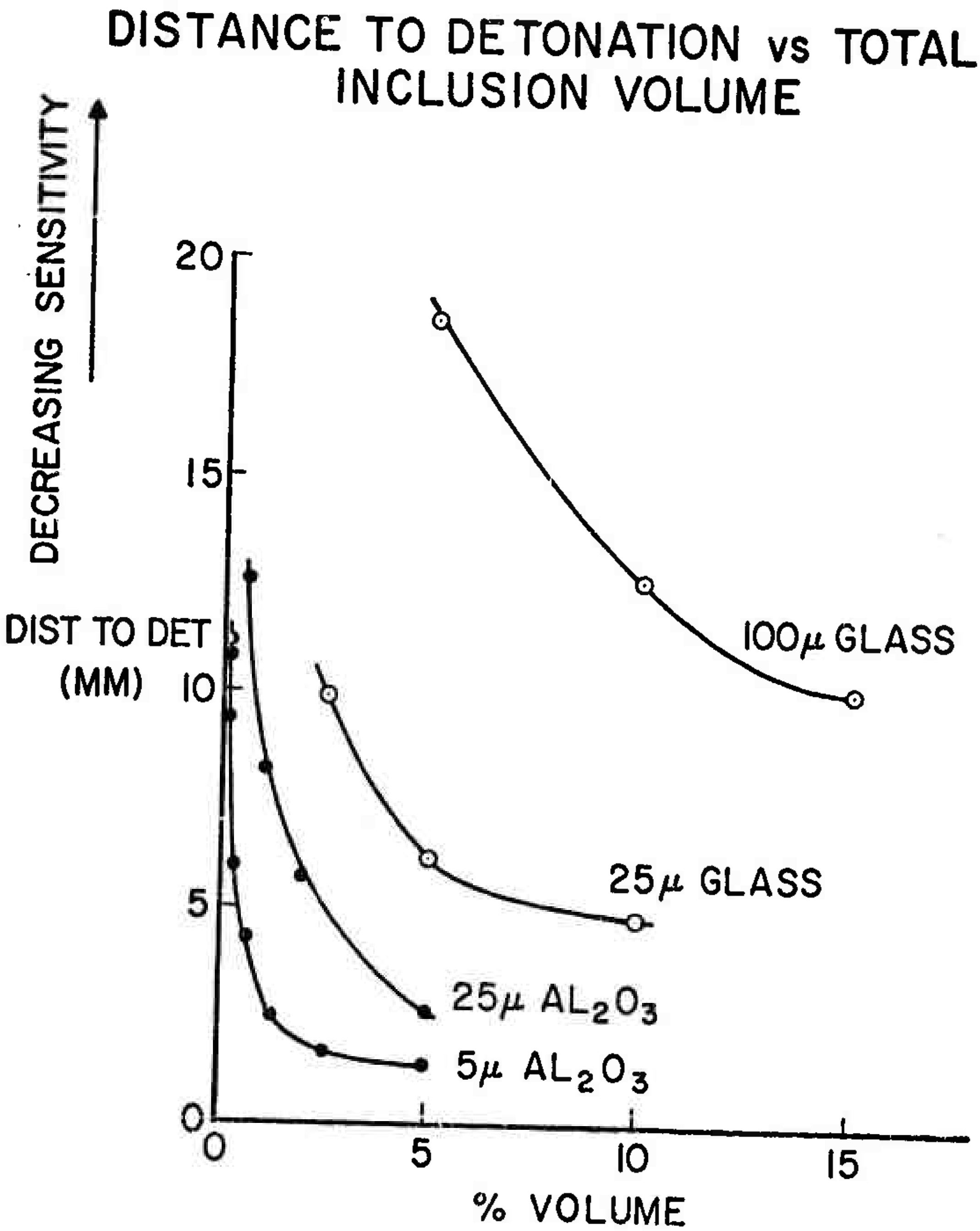


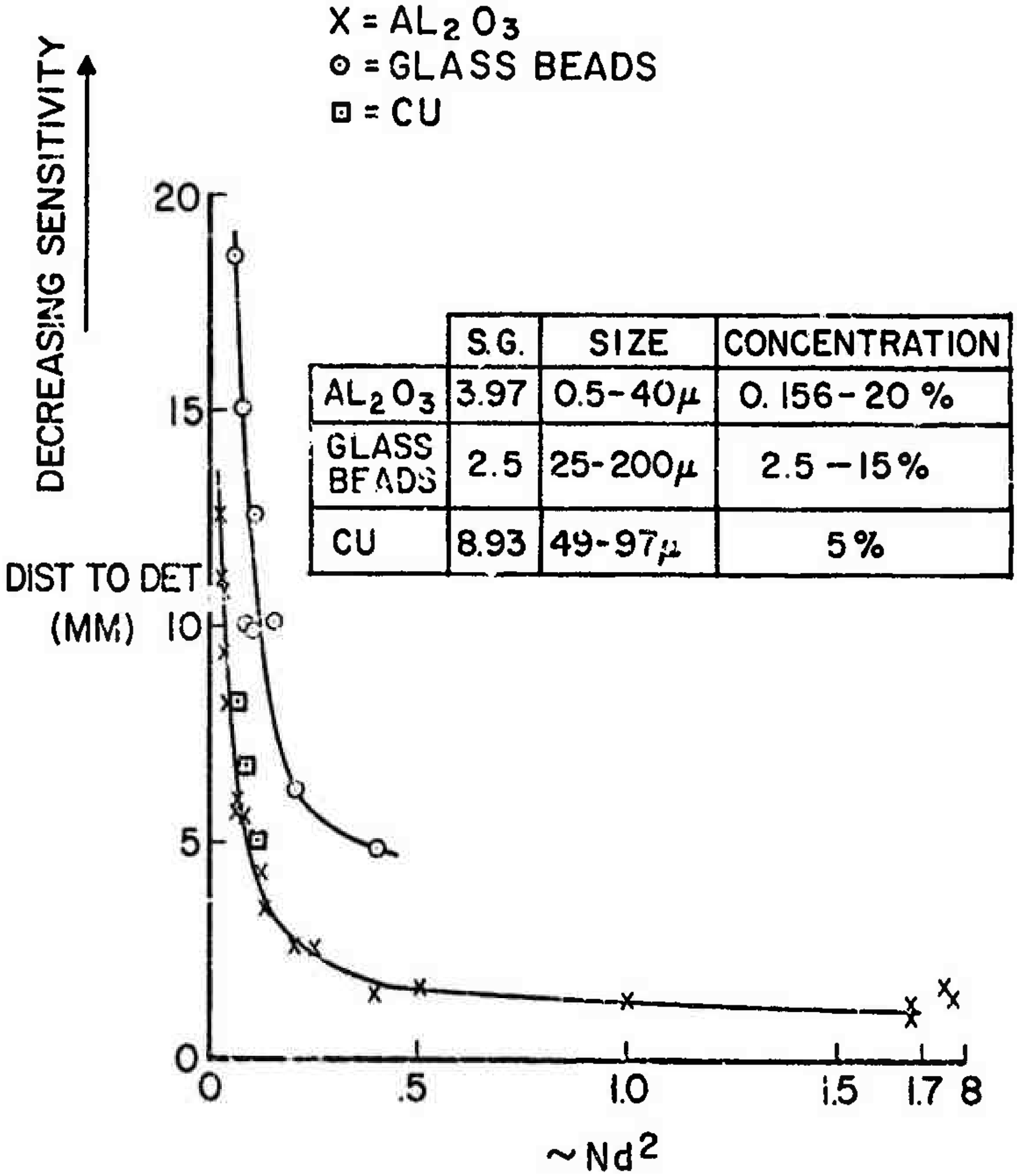
Figure 6



DISTANCE TO DETONATION vs TOTAL INCLUSION VOLUME
DECREASING SENSITIVITY
DIST TO DET (MM)
20
15
10
5
0
100μ GLASS
25μ GLASS
25μ AL2O3
5μ AL2O3
0
5
10
15
% VOLUME

Figure 7

TOTAL AREA vs DISTANCE TO DETONATION



	S.G.	SIZE	CONCENTRATION
AL_2O_3	3.97	0.5-40μ	0.156-20 %
GLASS BEADS	2.5	25-200μ	2.5 – 15%
CU	8.93	49-97μ	5%

Figure 8

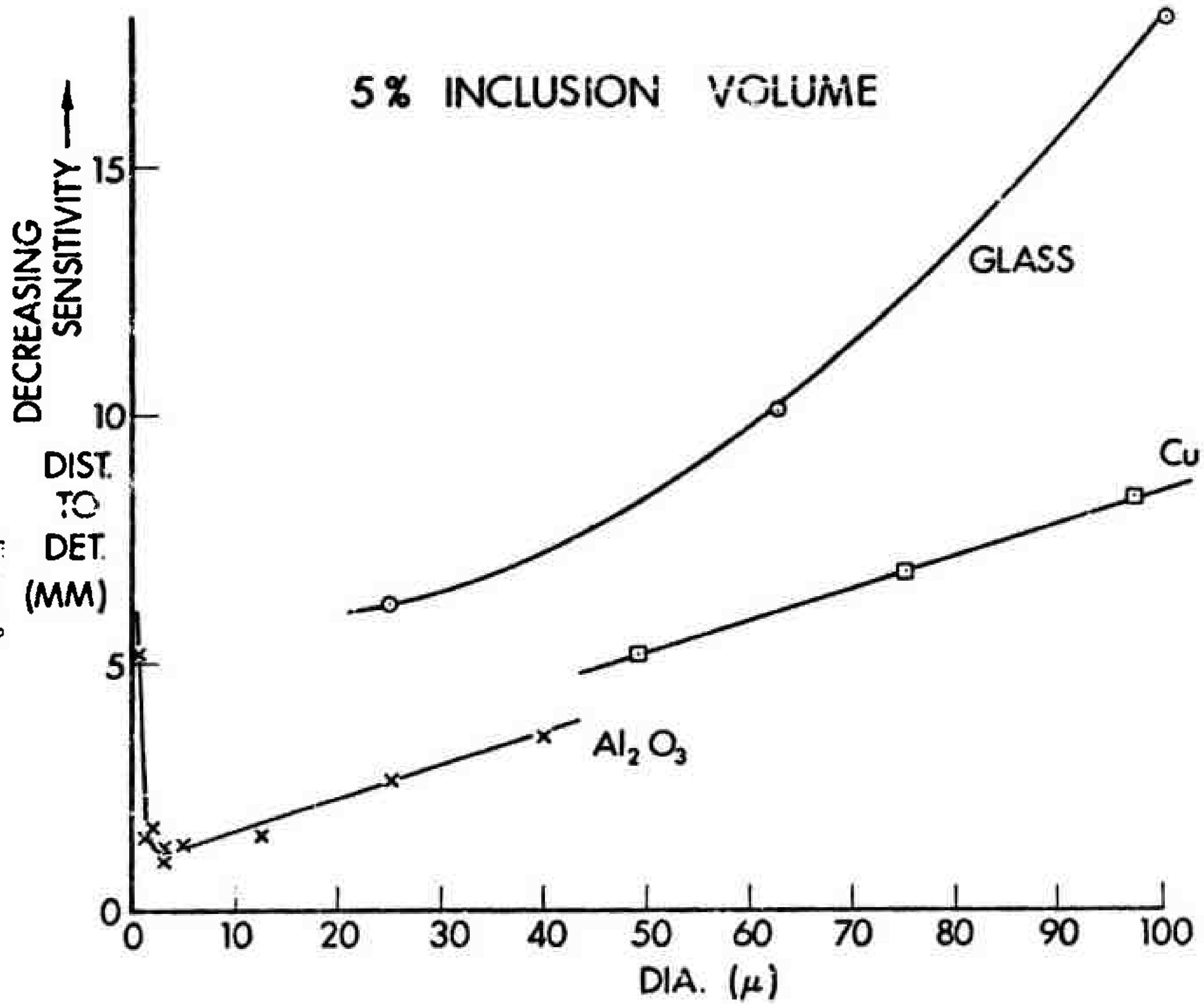
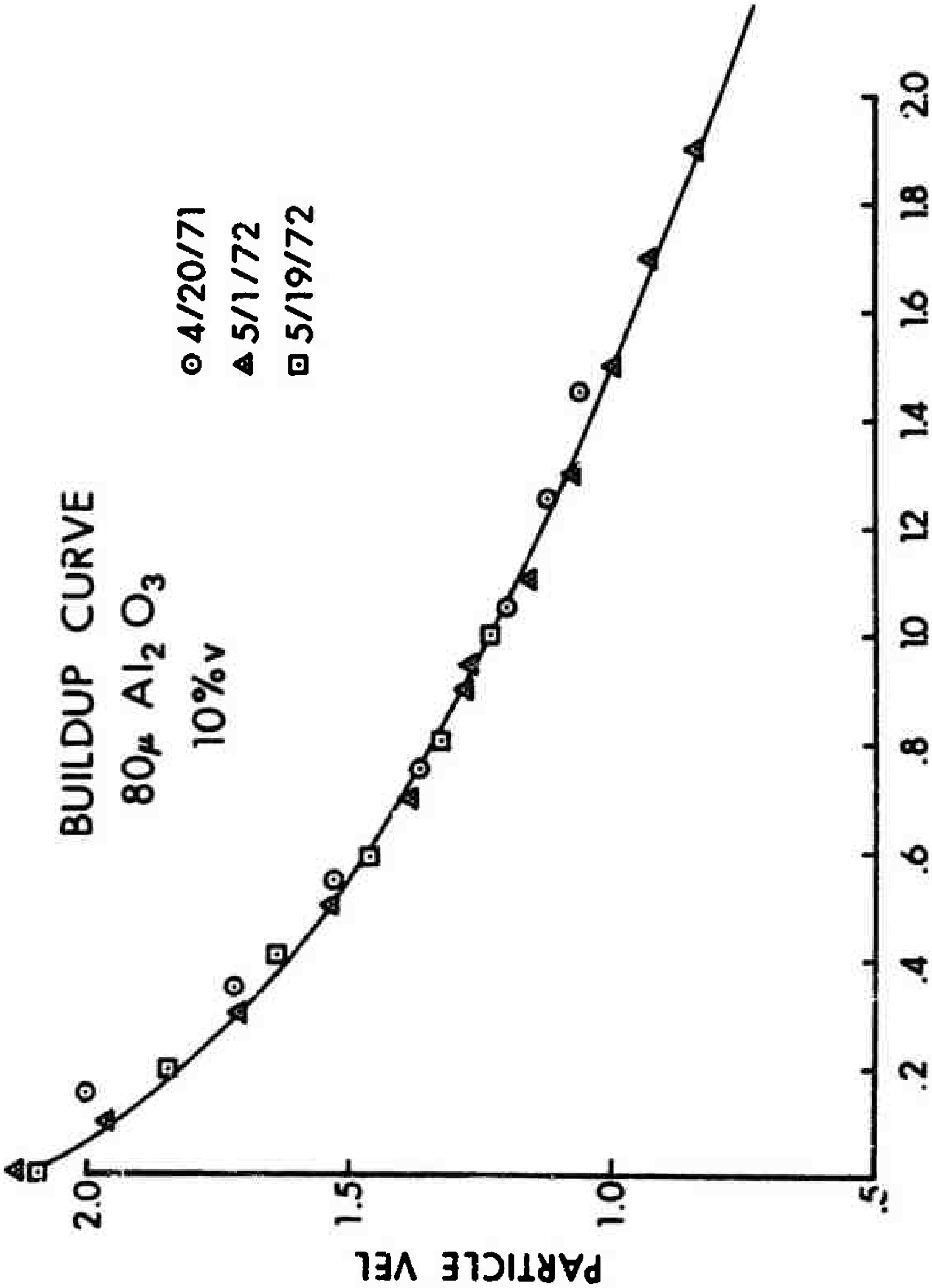

5 % INCLUSION VOLUME
DECREASING SENSITIVITY
DIST. TO DET. (MM)
15
10
5
0
GLASS
Cu
Al_2O_3
0
10
20
30
40
50
60
70
80
90
100
DIA. (μ)

Figure 9



BUILDUP CURVE
80μ Al2 O3
10%v
4/20/71
5/1/72
5/19/72
PARTICLE VEL
2.0
1.5
1.0
.5
Δt
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0

Figure 10

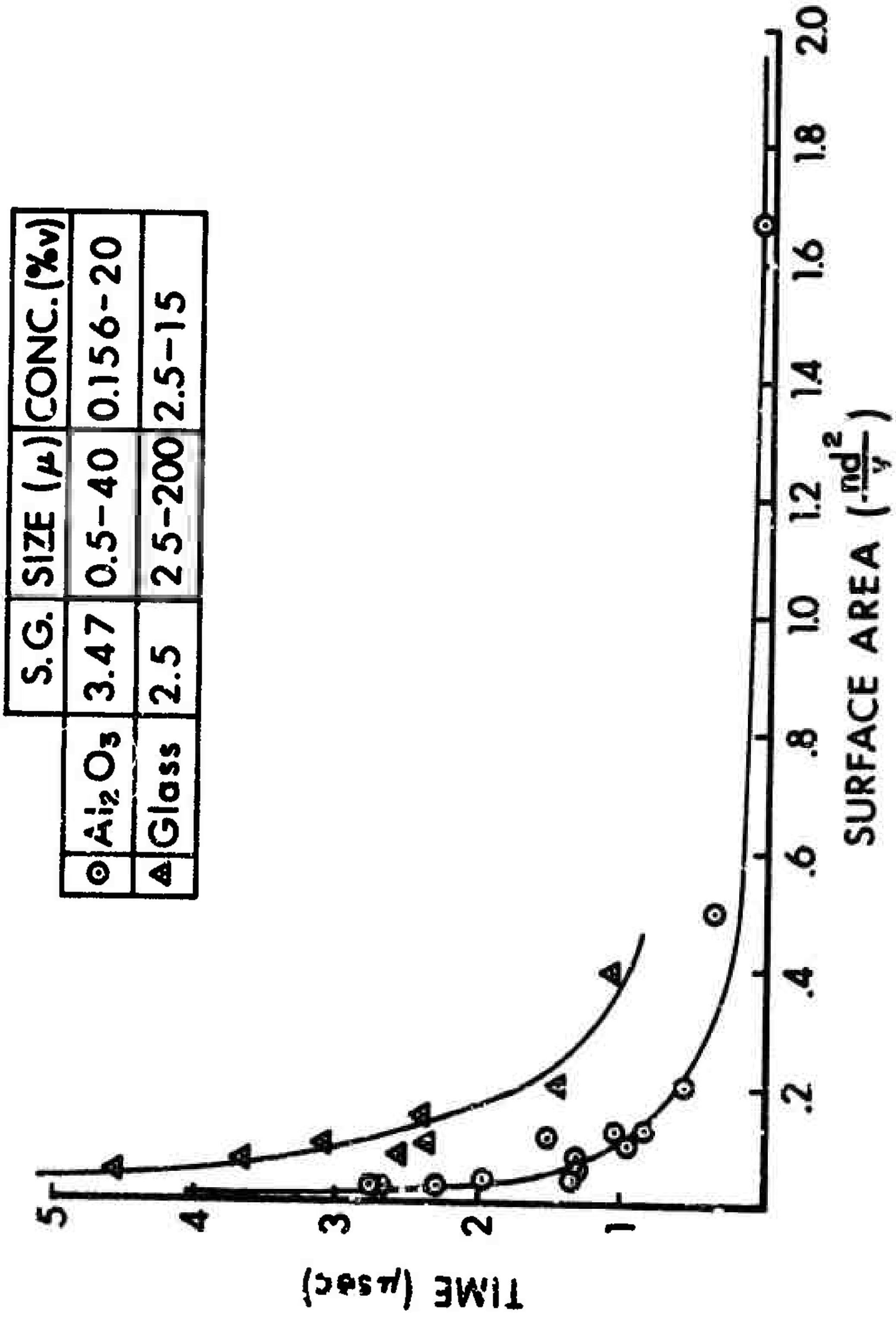
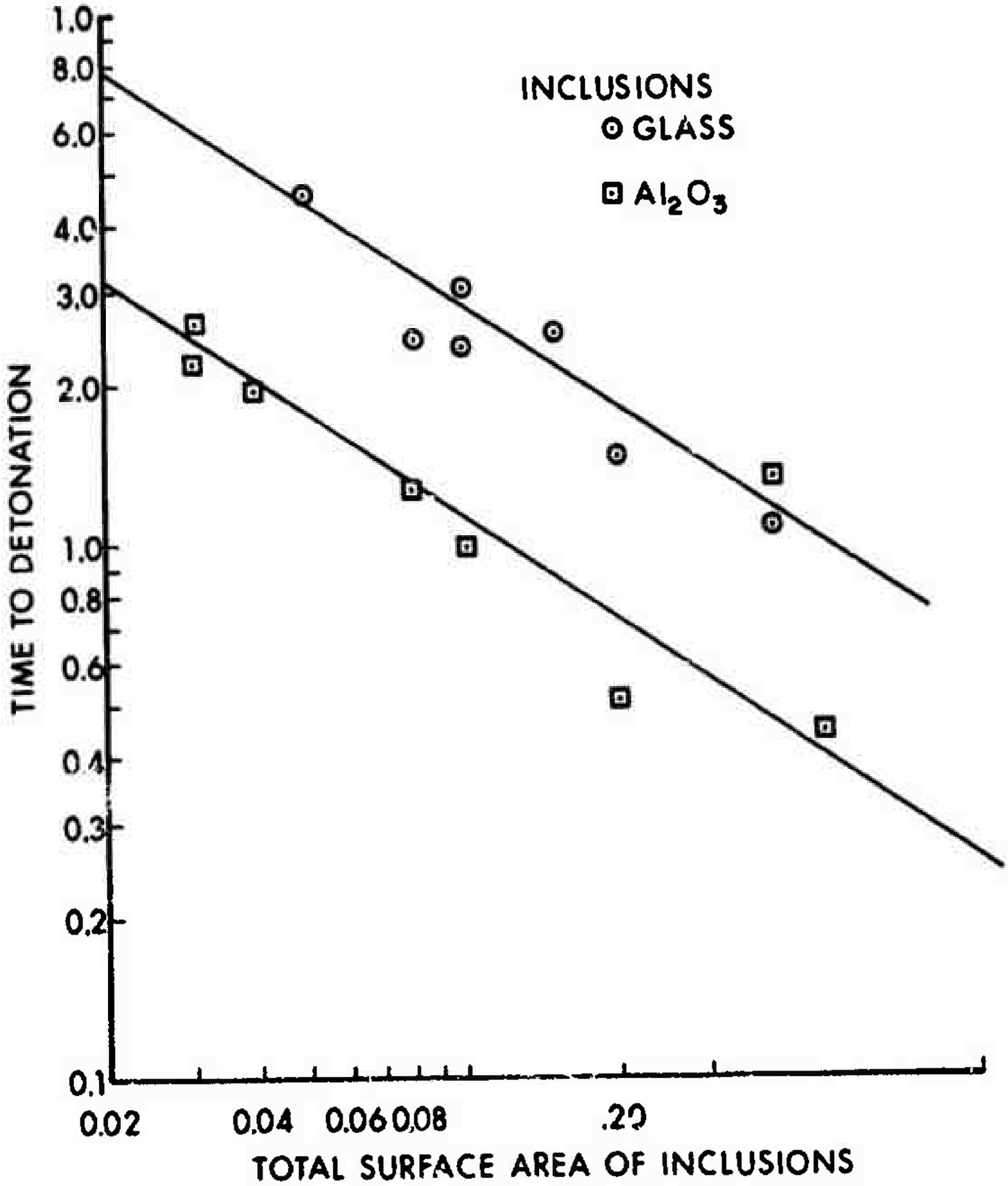

S.G.
SIZE (μ)
CONC. (%v)
Al₂O₃ 3.47 0.5–40 0.156–20
Glass 2.5 2.5–200 2.5–15
TIME (μsec)
SURFACE AREA (nd²/v)
1 2 3 4 5
.2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0

Figure 11



1.0
8.0
6.0
4.0
3.0
2.0
1.0
0.8
0.6
0.4
0.3
0.2
0.1
TIME TO DETONATION
INCLUSIONS
GLASS
Al_2O_3
0.02
0.04
0.06
0.08
.20
TOTAL SURFACE AREA OF INCLUSIONS

Figure 12

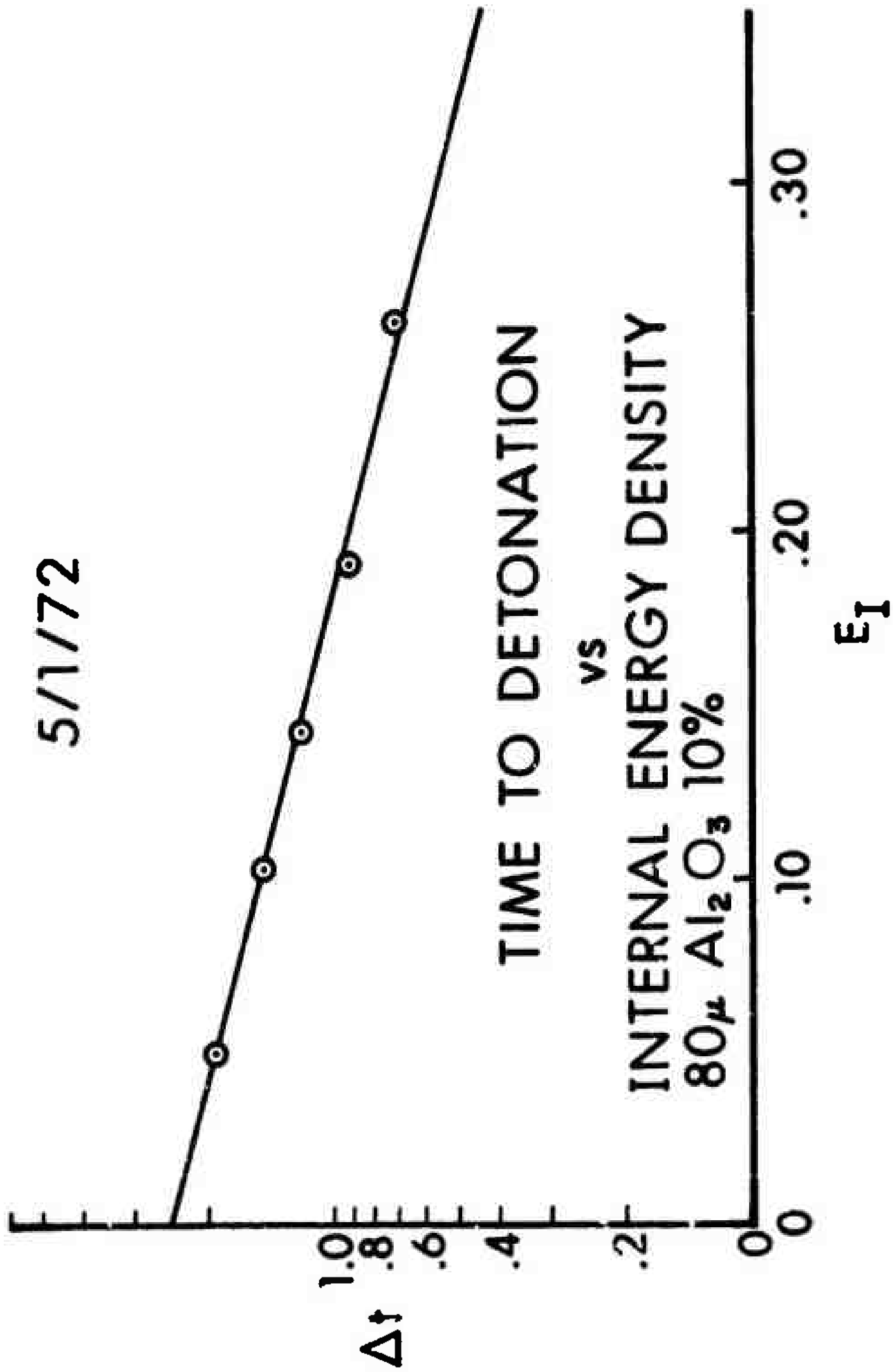

5/1/72
TIME TO DETONATION
vs
INTERNAL ENERGY DENSITY
80μ Al₂O₃ 10%
Δt
1.0 .8 .6 .4 .2 0
0 .10 .20 .30
E_I

Figure 13

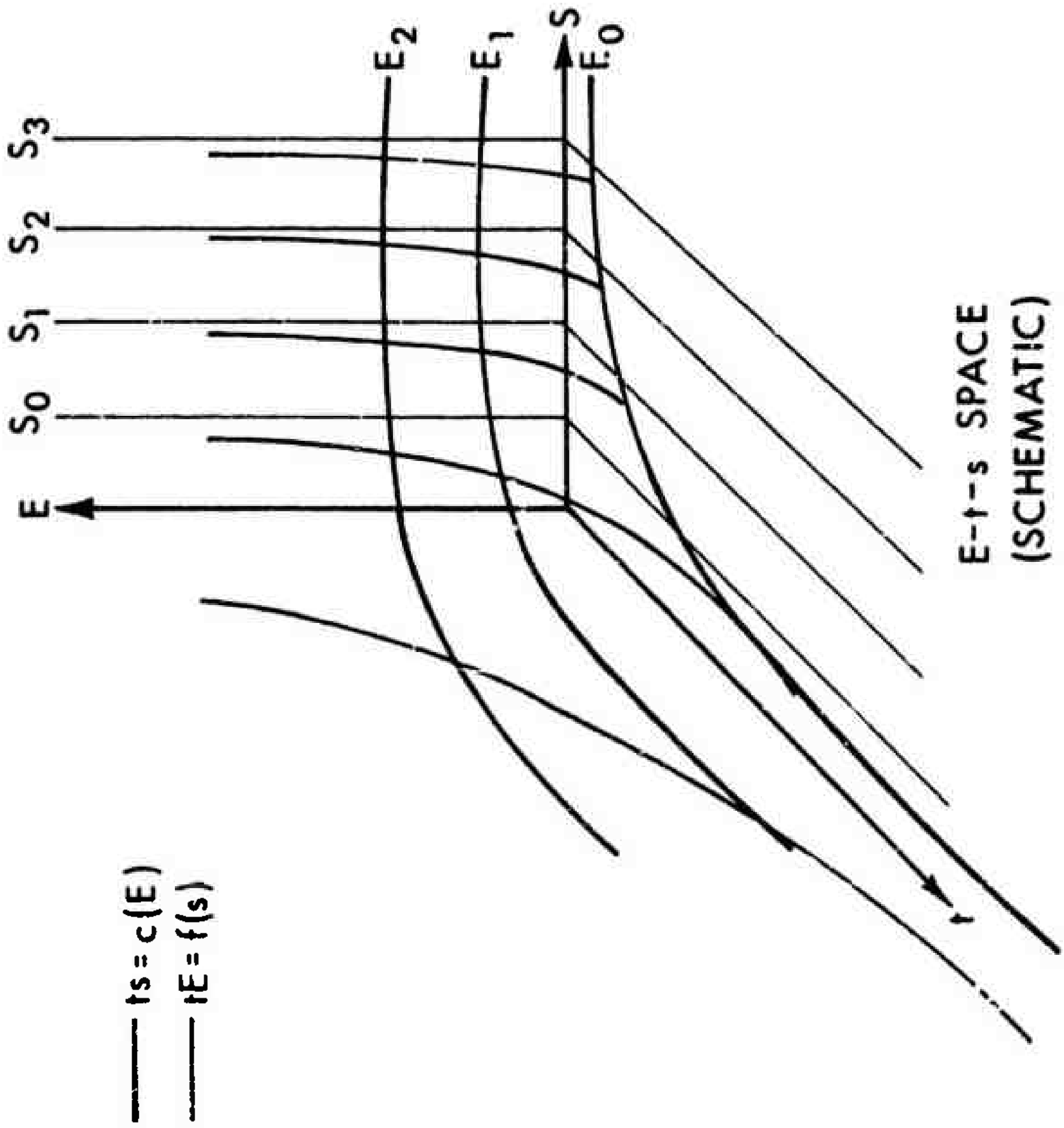


Figure 14

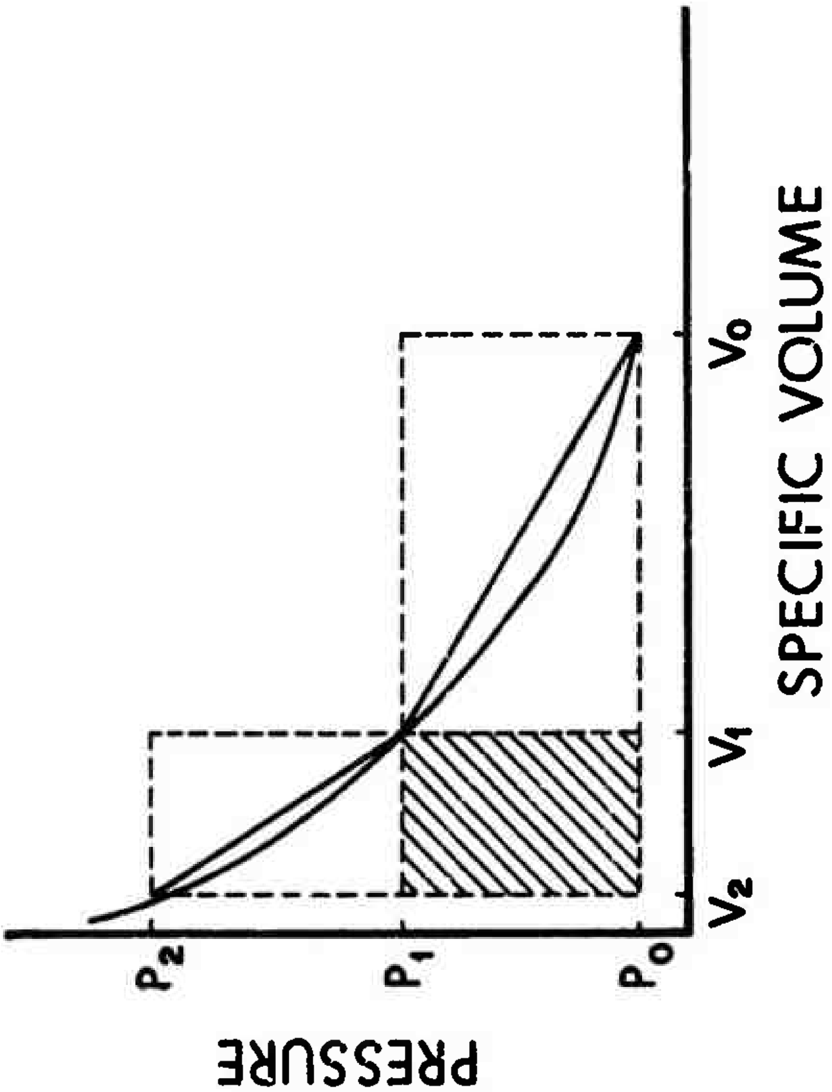
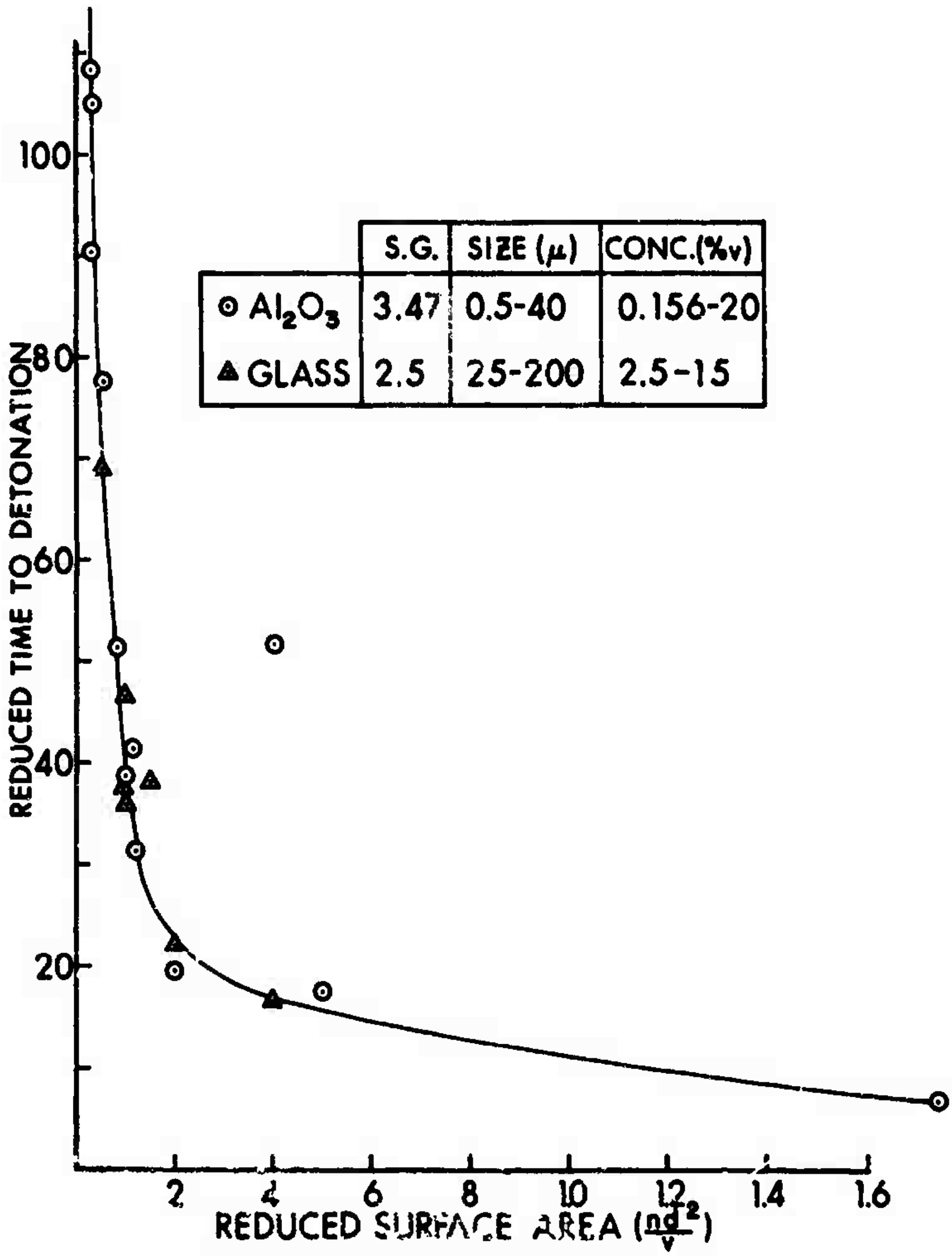


Figure 15



100
80
60
40
20
REDUCED TIME TO DETONATION
2
4
6
8
10
12
1.4
1.6
REDUCED SURFACE AREA ($\frac{nd^2}{v}$)
S.G.
SIZE (μ)
CONC.(%v)
⊙ Al_2O_3
3.47
0.5-40
0.156-20
▲ GLASS
2.5
25-200
2.5-15

Figure 1

SAFETY DESIGN TECHNOLOGY FOR PLANT MODERNIZATION

AN OVERVIEW

LEON W. SAFFIAN
DIRECTOR, MANUFACTURING TECHNOLOGY DIRECTORATE
PICATINNY ARSENAL
DOVER, N.J.

SUMMARY

THE SAFETY DESIGN MANUAL TM5-1300 ("STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS") DEVELOPED RECENTLY UNDER PICATINNY'S TECHNICAL DIRECTION AND DOD EXPLOSIVE SAFETY BOARD'S SPONSORSHIP, REPRESENTS A MAJOR STEP FORWARD IN PROTECTIVE CONSTRUCTION TECHNOLOGY. A CONTINUING MULTI-FACETED PROGRAM IS IN PROGRESS TO SUPPLEMENT TM-1300 AND AMCR 385-100 WITH INFORMATION AND DATA RELATING TO MINIMAL COST, STRUCTURAL TECHNIQUES AND TNT EQUIVALENCIES OF EXPLOSIVES, PROPELLANTS, PYROTECHNICS AND EXPLOSIVE END-ITEMS.

THIS PAPER COVERS TWO MAJOR AREAS OF THE SAFETY ENGINEERING STUDIES PROGRAM, NAMELY, (1) THE PROGRAM TO DEVELOP DESIGN DATA TO SUPPLEMENT TM5-1300 AND ARMY'S SAFETY MANUAL AMCR 385-100 AND (2) APPLICATION OF DESIGN CRITERIA IN CURRENT MODERNIZATIION PROGRAMS TO ASSIST U.S. ARMY MUNITIONS COMMAND (USAMUCOM) INSTALLATIONS IN THEIR FACILITY DESIGN LAYOUT.

VARIOUS PHASES OF THE SAFETY DESIGN CRITERIA PROGRAM ARE OUTLINED, AS WELL AS THE MANNER IN WHICH IT WILL BE INTEGRATED WITH NEW MANUFACTURING TECHNOLOGY FOR THE GOVERNMENT-OWNED CONTRACTOR OPERATED (GOCO) AMMUNITION PLANTS UNDER THE ARMY'S PLANT MODERNIZATION PROGRAM. THE REVIEW COVERS STUDIES RELATING TO WEAPON EFFECTS, STRUCTURAL RESPONSE, ACCEPTOR SENSITIVITY AND TNT EQUIVALENCY OF VARIOUS ENERGETIC, HAZARDOUS MATERIALS OF MILITARY INTEREST.

DETAILS OF VARIOUS PHASES OF THE SAFETY ENGINEERING PROGRAM ARE GIVEN IN INDIVIDUAL PAPERS INCLUDED IN THE 14TH ANNUAL EXPLOSIVE SAFETY SEMINAR. REFERENCE IS MADE TO THESE PAPERS IN THIS PRESENTATION.

INTRODUCTION

UNTIL RELATIVELY RECENTLY, PROTECTIVE MEASURES, i.e., SPACING BETWEEN EXPLOSIVE SYSTEMS, CONSTRUCTION OF PROTECTIVE WALLS AND BARRICADES, WERE DERIVED PRIMARILY FROM EXPERIENCE AND APPLIED JUDGMENT, RATHER THAN ENGINEERING PRINCIPLES. THE CRITERIA THAT WERE ESTABLISHED RESULTED FROM ANALYSES OF PREVIOUS ACCIDENTAL EXPLOSIONS. EXCEPT FOR A FEW ISOLATED CASES, CONSIDERATION WAS NOT GIVEN TO SEPARATE ANALYSIS OF THE VARIOUS DAMAGE MECHANISMS ASSOCIATED WITH EXPLOSIONS. UNDER THE TECHNICAL DIRECTION OF PICATINNY ARSENAL, A PROGRAM WAS UNDERTAKEN TO QUANTITATIVELY ESTABLISH DESIGN CRITERIA FOR STRUCTURES USED IN MANUFACTURING, PROCESSING AND STORAGE OF EXPLOSIVES. THE ENTIRE PROGRAM WAS SPONSORED AND FUNDED THROUGH THE DEPARTMENT OF DEFENSE EXPLOSIVE SAFETY BOARD (DODESB) BY THE THREE ARMED SERVICES AND THE DEFENSE NUCLEAR AGENCY.

THE OVERALL OBJECTIVE OF THE PROGRAM WAS TO ESTABLISH, THROUGH ANALYTICAL STUDIES SUPPORTED BY TESTING, QUANTITATIVE, REALISTIC DESIGN CRITERIA TO PREVENT EXPLOSION PROPAGATION, DAMAGE TO MATERIEL AND INJURY TO PERSONNEL. THE EXPERIMENTAL WORK INVOLVED MODEL AND FULL SCALE TESTING OF REINFORCED CONCRETE STRUCTURES AS WELL AS THEIR COMPONENTS. NEW DESIGNS WERE CONCEIVED AND THE THRESHOLD CAPACITIES OF VARIOUS STRUCTURAL CONFIGURATIONS WERE DETERMINED. THE VALIDITY OF THE USE OF SCALED MODEL TESTING TO REPLACE FULL SCALE TESTS WAS DEMONSTRATED.

THE PRODUCT OF THIS SYSTEMATIC ENGINEERING AND TEST PROGRAM WAS THE PUBLICATION OF A TRI-SERVICE REGULATORY SAFETY DESIGN MANUAL. THE MANUAL IS ENTITLED, "STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS" (TM5-1300, NAVFACP-397, AFM88-22). AN OUTLINE OF STUDIES LEADING TO PUBLICATION OF THE MANUAL IS SHOWN IN FIG 1. IT CONTAINS PROCEDURES, TABLES AND CHARTS REQUIRED TO ESTABLISH THE OUTPUT OF AN EXPLOSION IN ITS ENVIRONMENT, AND THE DAMAGING EFFECTS ON THAT ENVIRONMENT IN TERMS OF BLAST AND FRAGMENTS. THE RELATIONSHIPS ARE PRESENTED IN SUCH A MANNER THAT THE TYPE OF PROTECTIVE STRUCTURE REQUIRED MAY BE SELECTED, ANALYZED AND DESIGNED TO PROVIDE SAFE LEVELS OF PROTECTION FOR PERSONNEL AND EQUIPMENT, AS WELL AS SAFE SEPARATION OF POTENTIALLY MASS-DETONATING MATERIALS.

THE ARMY'S GOCO PLANT MODERNIZATION PROGRAM WHICH ENCOMPASSES ALL AREAS OF AMMUNITION PRODUCTION (i.e. PROPELLANTS AND EXPLOSIVES MANUFACTURE AS WELL AS LOADING, ASSEMBLY AND PACKING (LAP) OPERATIONS) WAS INITIATED AROUND THE SAME TIME THAT TM5-1300 WAS PUBLISHED. HENCE, NUMEROUS GOCO ESTABLISHMENTS REQUIRED AND RECEIVED GUIDANCE IN THE PREPARATION OF THEIR NEW FACILITY DESIGN CONCEPTS TO INCORPORATE THE PROTECTIVE DESIGN CRITERIA. IN THE COURSE OF THESE APPLICATIONS OF THE MANUAL TO THE PLANT MODERNIZATION PROGRAM IT WAS FOUND THAT THE DATA SUPPLIED IN THE MANUAL WERE QUITE CONSERVATIVE. WHENEVER SPECIFIC INFORMATION WAS NOT AVAILABLE, e.g. EFFECTS OF BLAST PRESSURE LEAKAGE, VENTING, FRANGIBILITY ETC., THE MOST CONSERVATIVE APPROACH WAS USED. ALTHOUGH SAFETY REQUIREMENTS WERE FULLY MET, IT WAS EVIDENT THAT ADDITIONAL ECONOMIES IN CONSTRUCTION COST COULD BE REALIZED. ALSO, THE PRESENT DESIGN STANDARDS AS CONTAINED IN TM5-1300 ARE BASED ON EFFECTS OF BARE SPHERICAL

TNT CHARGES AND IT WAS RECOGNIZED THAT ADDITIONAL DATA WOULD BE REQUIRED RELATIVE TO ACTUAL IN-PROGESS AND END-ITEM EXPLOSIVE CONFIGURATIONS, AS WELL AS TNT EQUIVALENCIES OF OTHER ENERGETIC, HAZARDOUS MATERIALS. THE DEVELOPMENT OF NEW TECHNOLOGY AND MANUFACTURING CONCEPTS UNDER THE PLANT MODERNIZATION PROGRAM ALSO POINTED TO THE NEED FOR MORE DEFINITIVE INFORMATION PERTAINING TO SAFE SPACING AND/OR SHIELDING OF IN-PROCESS MATERIALS AND MUNITIONS. TO PROVIDE THE ADDITIONAL DESIGN CRITERIA REQUIRED, A BROAD PROGRAM ENTITLED "SAFETY ENGINEERING IN SUPPORT OF AMMUNITION PLANTS" WAS INITIATED BY PICATINNY ARSENAL AND ENDORSED BY THE DODESB.

AN OUTLINE OF THE CURRENT PROGRAM IS SHOWN IN FIG 2. THE TASKS ARE GROUPED UNDER TWO MAJOR CATEGORIES, NAMELY:

A. DEVELOPMENT OF DESIGN CRITERIA TO SUPPLEMENT AND MODIFY SAFETY MANUAL AMCR 385-100 AND SAFETY DESIGN MANUAL TM5-1300.

B. APPLICATION OF DESIGN CRITERIA TO CURRENT MODERNIZATION PROGRAMS TO ASSIST MUCOM INSTALLATIONS IN THEIR FACILITY DESIGN.

TNT EQUIVALENCY

ONE OF THE MOST URGENT AND CRITICAL AREAS IN OUR OVERALL PROGRAM, IS THE ESTABLISHMENT OF TNT EQUIVALENCIES OF EXPLOSIVES, PROPELLANTS, PYROTECHNICS AND EXPLOSIVE END ITEMS (FIG 3). TO DATE, TESTING OF TNT EQUIVALENCY OF BLACK POWDER, BOTH IN-PROCESS & FINISHED PRODUCT, HAS BEEN COMPLETED. SUBSTANTIAL REDUCTION IN OVERALL SPACE AND QUANTITY-DISTANCE REQUIREMENTS WILL BE REALIZED AS A RESULT OF THESE TESTS. THE FIRST GOVERNMENT-OWNED BLACK POWDER MANUFACTURING PLANT TO BE CONSTRUCTED IN THE NEAR FUTURE, WILL

BE BASED ON SAFETY DESIGN CRITERIA ESTABLISHED AS A RESULT OF THESE TESTS. TNT EQUIVALENCY STUDIES HAVE ALSO BEEN COMPLETED FOR CYLINDRICAL COMPOSITION B, AND M1 AND N5 PROPELLANTS. TESTING OF M8 PROPELLANT, RDX SLURRY, NITRO-GUANIDINE, GUANIDINE-NITRATE, SEVERAL PYROTECHNIC COMPOSITIONS AND OTHER HAZARDOUS MATERIALS IS EITHER IN PROGRESS OR WILL BE INITIATED SHORTLY. AT THE SAME TIME A HANDBOOK IS BEING PREPARED DESCRIBING PROCEDURES TO BE FOLLOWED IN PERFORMING TNT EQUIVALENCY TESTS OF ANY ENERGETIC HAZARDOUS MATERIAL. MRS. H. NAPADENSKY OF IIT RESEARCH INSTITUTE COVERS THIS PHASE OF OUR OVERALL PROGRAM IN MORE DETAIL AT THIS SEMINAR IN A PAPER ENTITLED, "TNT EQUIVALENCIES OF SELECTED EXPLOSIVES, PROPELLANTS & PYROTECHNICS".

ACCEPTOR SENSITIVITY

THE ACCEPTOR SENSITIVITY PHASE OF THE PROGRAM IS SHOWN IN FIG 4. TO DATE, SAFE SEPARATION DISTANCES ON A CONVEYOR FOR SEVERAL AMMUNITION ITEMS (FIG 5) HAVE BEEN ESTABLISHED. THESE INCLUDE: 155MM COMPOSITION B-LOADED PROJECTILES, 2.75" ROCKETS AND M18 MINES. TESTS ON 81MM SHELL ARE IN PROGRESS. SAFE SEPARATION DISTANCES HAVE ALSO BEEN ESTABLISHED FOR IN-PROCESS EXPLOSIVES (FIG 6) SUCH AS 55 POUND BOXES OF TNT, C4 BLOCKS ON A CONVEYOR AND BULK C4 IN BUCKETS. TESTS ON 60 POUND BOXES OF COMPOSITION B ARE CURRENTLY IN PROGRESS. DETAILS OF THESE TESTS ARE COVERED AT THIS SEMINAR IN MR. RINDNER'S PRESENTATION ENTITLED, "EXPLOSIVES AND AMMUNITION SENSITIVITY TESTS".

WEAPON EFFECTS

THE WEAPON EFFECTS TEST PROGRAM IS SHOWN IN FIG 7. TO DATE, WORK IS IN PROGRESS ON VARIATION OF INTERNAL BLAST PRESSURES WITHIN A PROTECTIVE STRUCTURE WITH VENTING AREA AND FRANGIBILITY (FIG 8), EVALUATION OF LEAKAGE PRESSURES PRODUCED BY EXPLOSIONS IN FULLY OR PARTIALLY VENTED CUBICLES (FIG 9) AND EVALUATION OF DEBRIS EFFECTS DUE TO EXPLOSIONS (FIG 10). MR. W. KEENAN OF THE NAVAL CIVIL ENGINEERING LABORATORY (NCEL), PORT HUENEME, CALIFORNIA COVERS THESE THREE SUBJECTS IN A PAPER ENTITLED, "BLAST PRESSURE LEAKAGE PRODUCED BY PARTLY CONFINED EXPLOSIONS", WHICH IS INCLUDED IN THIS SEMINAR.

STRUCTURAL RESPONSE

AN OUTLINE OF THIS PLANNED PHASE OF WORK IS SHOWN IN FIGS 11 and 12. IT DEALS WITH STRUCTURAL RESPONSES OF REINFORCED CONCRETE, STEEL, AND OTHER BLAST ATTENUATING MATERIALS, AS WELL AS STRUCTURAL MOTIONS AND RESPONSES OF SPECIFIC STRUCTURES, e.g. T-BARRICADES AND BELOW-GRADE CONFIGURATIONS.

PREPARATION OF DESIGN CRITERIA SUPPLEMENTS

THE PREPARATION OF SUPPLEMENTS TO AMCR 385-100 AND TM5-1300 (FIG 13) INCLUDES:

A. PREPARATION OF PRELIMINARY DESIGN CHARTS AND COST INFORMATION FOR REINFORCED CONCRETE CUBICLES USED IN FACILITY PLANNING. THIS REPORT HAS BEEN COMPLETED AND WILL BE RECOMMENDED TO DODESB FOR APPROVAL AS A SUPPLEMENT TO TM5-1300. MR. N. DOBBS OF AMMANN & WHITNEY DISCUSSES THIS

SUBJECT AT THIS SEMINAR IN A PAPER ENTITLED, "DESIGN AND COST EVALUATION CHARTS FOR USE IN PRELIMINARY DESIGN OF LACED REINFORCED CONCRETE ELEMENTS".

B. PREPARATION OF SAFETY CONCEPTS FOR USE IN MODERNIZATION OF USAMUCOM FACILITIES DESCRIBING PROPOSED NEW SAFETY REGULATIONS TO BE INCORPORATED IN THE DESIGN OF ALL MODERNIZED EXPLOSIVE MANUFACTURING AND LAP FACILITIES. THESE CONCEPTS HAVE BEEN RECOMMENDED TO DODESB FOR APPROVAL AS A SUPPLEMENT AND/OR MODIFICATION TO AMCR 385-100. MR. FORSTEN WILL COVER THESE CONCEPTS DURING THIS SEMINAR IN A PAPER ENTITLED, "APPROVED SAFETY CONCEPTS FOR USE IN MODERNIZATION OF USAMUCOM INSTALLATIONS".

C. PREPARATION OF A REPORT CONTAINING DESIGN CHARTS TO DETERMINE OVERTURNING AND SLIDING OF CUBICLE TYPE STRUCTURES. PREPARATION OF THIS REPORT IS IN PROGRESS AND WILL BE RECOMMENDED AS A SUPPLEMENT TO TM5-1300 WHEN COMPLETED.

APPLICATION OF PROTECTIVE DESIGN CRITERIA

FIG 14 OUTLINES THE TASKS INVOLVED IN APPLICATION OF PROTECTIVE DESIGN CRITERIA TO CURRENT MODERNIZATION PROGRAMS. THE PURPOSE IS TO ASSIST USAMUCOM FACILITIES IN (A) PREPARATION OF CONCEPT STUDIES (B) REVIEW AND EVALUATION OF FACILITY DESIGNS AND (C) SPECIAL PROJECTS. SOME OF THE PROGRAMS IN WHICH ASSISTANCE HAS BEEN RENDERED TO OTHER GOVERNMENT FACILITIES ARE LISTED. FURTHER BREAKDOWNS RELATING TO EACH OF THESE PHASES OF WORK ARE SHOWN IN FIGS 15, 16, 17, and 18. DETAILS OF SOME SPECIFIC FACILITY REVIEWS AND EVALUATIONS ARE DISCUSSED BY MR. N. DOBBS OF AMMANN & WHITNEY, CONSULTING ENGINEERS IN A PAPER ENTITLED, "APPLICATION OF NEW SAFETY CRITERIA IN EXPLOSIVE MANUFACTURING FACILITY DESIGN", WHICH IS INCLUDED IN THIS SEMINAR.

CLOSING REMARKS

FIG 19 SUMMARIZES ACCOMPLISHMENTS AND STATUS TO-DATE OF THE OVERALL PROGRAM. THE SAFETY ENGINEERING PROGRAM IS A PARTICULARLY SIGNIFICANT EXAMPLE OF ADVANCED TECHNOLOGY BEING DEVELOPED TO SUPPORT THE GOCO PLANT MODERNIZATION PROGRAM. A MEANINGFUL BASIS FOR PROTECTIVE DESIGN IS NOW AVAILABLE FOR DESIGN OF STRUCTURES TO HOUSE PRODUCTION LINES ESTABLISHED AS A RESULT OF THE PLANT MODERNIZATION EFFORTS. A COMPREHENSIVE ENGINEERING PROGRAM IS UNDERWAY TO SUPPLEMENT AND REFINE THE SIGNIFICANT RESULTS ALREADY ACHIEVED. WE FEEL CONFIDENT THAT WITH THE CONTINUED ASSISTANCE OF OTHER GOVERNMENT AGENCIES AND PRIVATE INDUSTRY, THIS VITAL ENTERPRISE WILL SUCCEED.

OUTLINE OF STUDIES LEADING TO TM5-1300

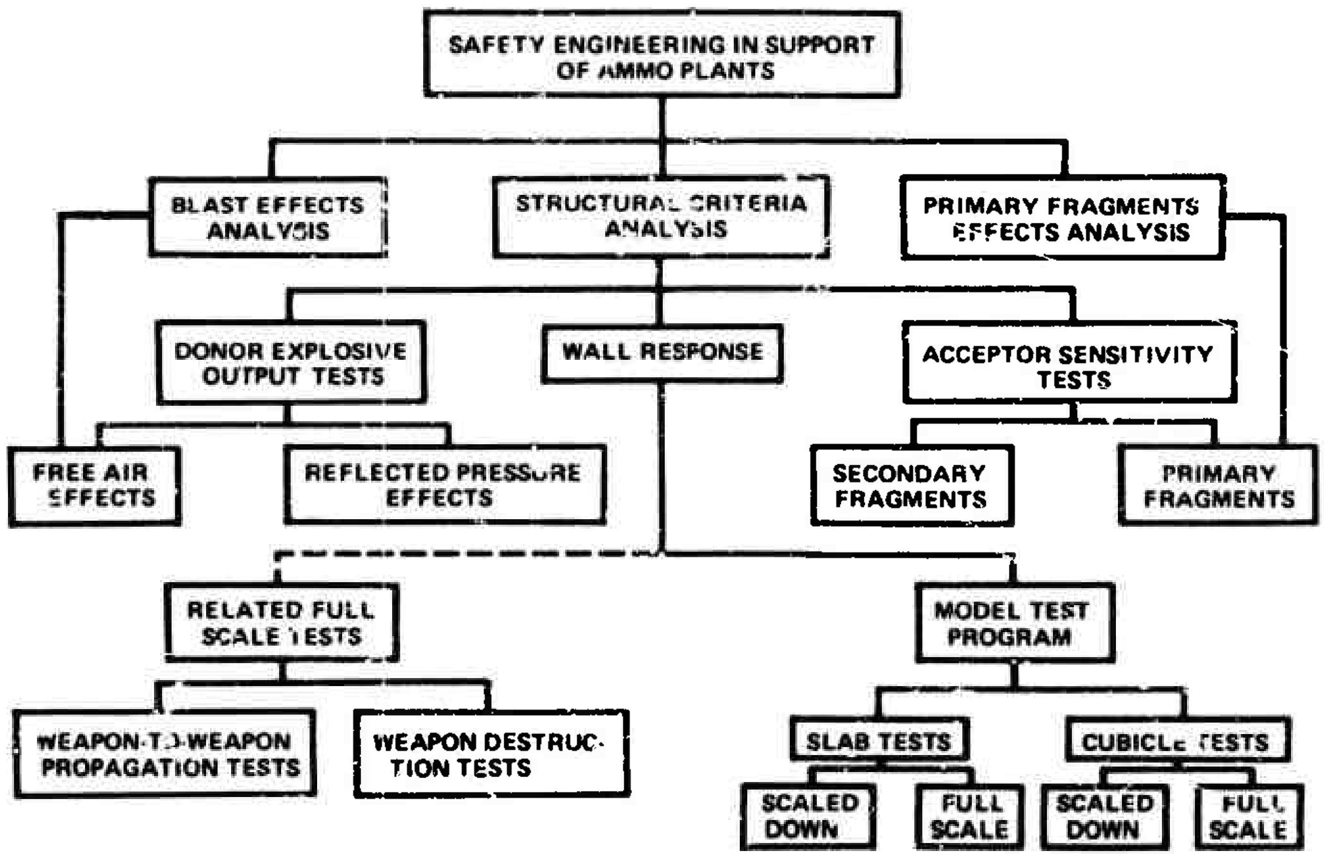


FIG 1

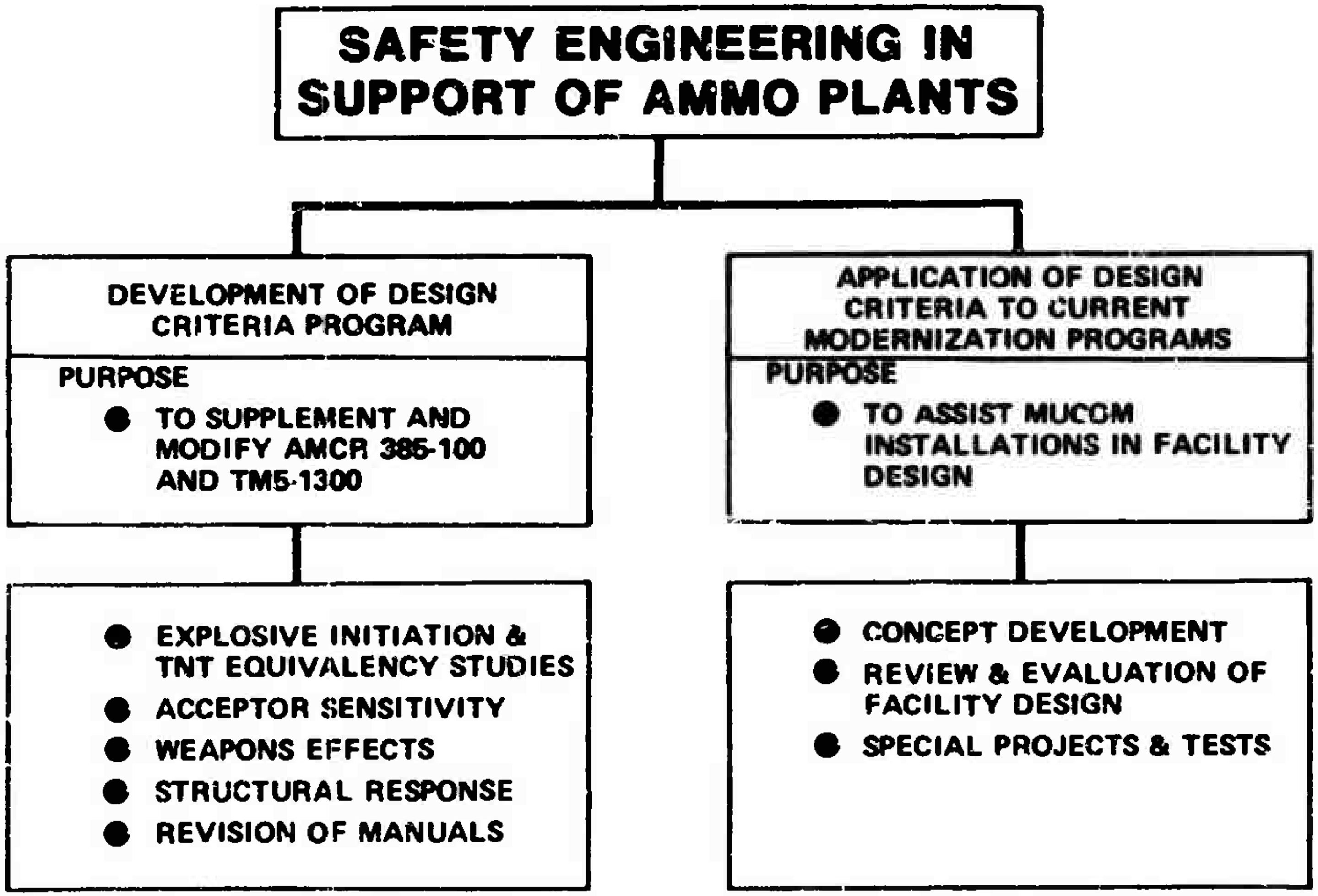

SAFETY ENGINEERING IN SUPPORT OF AMMO PLANTS
DEVELOPMENT OF DESIGN CRITERIA PROGRAM
PURPOSE
TO SUPPLEMENT AND MODIFY AMCR 385-100 AND TM5-1300
EXPLOSIVE INITIATION & TNT EQUIVALENCY STUDIES
ACCEPTOR SENSITIVITY
WEAPONS EFFECTS
STRUCTURAL RESPONSE
REVISION OF MANUALS
APPLICATION OF DESIGN CRITERIA TO CURRENT MODERNIZATION PROGRAMS
PURPOSE
TO ASSIST MUCOM INSTALLATIONS IN FACILITY DESIGN
CONCEPT DEVELOPMENT
REVIEW & EVALUATION OF FACILITY DESIGN
SPECIAL PROJECTS & TESTS

FIG 2

TEST PROGRAM TO SUPPLEMENT AMCR 385-100 & TM5-1300

EXPLOSIVE INITIATION & TNT EOUIVALENCY STUOY

PURPOSE	STATUS
EXPLOSIVES	TESTING WITH BLACK POWDER COMPL. RESULTS SHOW LOWER VALUES OF TNT EOUIV THAN PRESENTLY USED REPORT COMPL TESTING OF CYL COMP B & RDX SLURRY COMPL FINAL REPORT IN PROGRESS
PROPELLANTS	TESTING OF IN-PROCESS N-5 & M1 PRPLT (SINGLE ITEM AND PALLETS) COMPL REPORT COMPL TESTING OF M-8 PRPLT AND NITROGUANIDINE AND CRITICAL HEIGHT TESTS OF M-1 PRPLT SCHEOULEO SHORTLY
PYROTECHNICS	TEST PLAN FOR 2 ILLUMINATING COMPSN & FIRST FIRE COMPSN PREPARED. CONTRACT BEING NEGOTIATEO, TESTING SCHEOULEO SHORTLY
ADDIT TNT EOUIV TESTING	PROPOSAL IS BEING REVIEWED TO PERFORM ADDITIONAL TNT EOUIV TESTS OF TEN (10) XPLS, PRPLTS AND/OR ENO ITEMS
ESTAB PROCEDURE FOR TNT EOUIV TESTING	PREPARATION OF A HANDBOOK DESCRIBING PROCEDURES FOR PERFORMING TNT EQUIV TESTS-TO BE INITIATED SHORTLY

FIG 3

TEST PROGRAM
TO SUPPLEMENT & MODIFY
AMCR 385-100 & TM5-1300

ACCEPTOR SENSITIVITY

- ESTAB SAFE SEPAR DISTANCE FOR END ITEMS ON A CONVEYOR
- ESTAB SAFE SEPAR DISTANCE FOR IN-PROCESS EXPLOSIVES ON A CONVEYOR
- ESTAB A COMPUTER MODEL TO DETERMINE SAFE SEPAR OF END ITEMS
- ESTAB IMPACT SENSITIVITY OF END-ITEMS TO SECONDARY (CONCRETE) FRAGMENTS
- ESTAB IMPACT SENSITIVITY OF IN-PROCESS EXPLOSIVES TO SECONDARY (CONCRETE) FRAGMENTS
- ESTAB A STANDARDIZED TEST PROCEDURE FOR MEASUREMENT OF ACCEPTOR SENSITIVITY TO SECONDARY FRAGMENT IMPACT

FIG 4

ACCEPTOR SENSITIVITY

ESTABLISHMENT OF SAFE SEPARATION DISTANCE FOR AMMO ITEMS

PURPOSE	STATUS
ESTAB SAFE SEPAR DISTANCE AND/OR SHIELDING OF 155MM COMP B LOADED SHELL ON CONVEYOR	• TESTS SHOWED A MIN 8 FT SAFE SEPAR REQD WHEN SHIELDING IS NOT PROVIDED • ½" STL; 1" AL SHIELDING AND/OR 2" STL ROD PREVENTED DETON PROPAG AT 18" SEPAR • CONFIRMATORY TESTS WITH ½" STL COMPL TECH REPORT COMPL
ESTAB SAFE SEPAR DISTANCE AND/OR SHIELDING FOR OTHER AMMO ITEMS	• TESTS OF 2.75" ROCKETS COMPL INDICATING MIN 9" SEPAR USING 3/8" STL PLATES OR 2" DIA ROD IS REQD TECH REPORT COMPL • TESTS OF M18 MINES COMPL INDICATING 12" MIN SAFE SEPAR REQD • TESTS OF 81MM PROJECTILES PRESENTLY IN PROGRESS • TESTS WITH 105MM AND 8" PROJECTILES – PLANNED

FIG 5

ACCEPTOR SENSITIVITY

ESTABLISHMENT OF SAFE SEPARATION DISTANCE FOR IN-PROCESS EXPLOSIVES

PURPOSE	STATUS
TO DETERMINE SAFE SEPAR DISTANCE FOR 55 LBS TNT LOADED BOXES ON CONVEYOR	● TEST & REPORT COMPL.NO PROPAGATION AT 10 FT SEPAR BETWEEN BOXES.FIRES OCCURRED UP TO 16 FT SEPAR ● CONFIRMATORY TESTS USING 12FT SEPAR DISTANCES COMPL
TO DETERMINE SAFE SEPAR DISTANCES OF COMP B LOADED BOXES	● TEST PLAN FOR 60 LB COMP "B" BOXES PREPARED TEST SERIES SIMILAR TO TNT BOXES SCHEDULED SHORTLY
TO DETERMINE SAFE SEPAR DISTANCE FOR C-4 BLOCKS AND C-4 BUCKETS	● TESTS OF C-4 BLOCKS (1½ LBS) COMPL INDICATING SAFE SEPAR DISTANCE OF 10" BETWEEN BLOCKS ● TESTS OF C-4 BUCKETS (100 LBS) SCHEDULED TO BEGIN SHORTLY

FIG 6

PROGRAM TO SUPPLEMENT & MODIFY TM5-1300

WEAPON EFFECTS TEST PROGRAM

- EVLTN OF INTERNAL BLAST PRESSURES
- EVLTN OF LEAKAGE PRESSURES
- PRESSURE BUILD UP IN STRUCTURES (DUE TO EXTERNAL BLAST)
- PRESSURE FLOW IN TUNNELS & DUCTS
- EFFECTS PRODUCED BY STRUCTURAL BURIAL
- EVLTN OF DEBRIS EFFECTS DUE TO EXPLOSIONS

FIG 7

WEAPONS EFFECTS

INTERNAL BLAST PRESSURES CAUSED BY VARIATION OF VENTING AREA AND FRANGIBILITY

OBJECTIVE	STATUS
CLASSIFY STRL CONFIG AS FULLY VENTED	TESTS COMPL & REPORT IN PREP. RESULTS INDICATE AT LEAST ONE SIXTH OF CUBICLE SURFACE AREA MUST BE FULLY VENTED TO PREVENT GAS PRESSURE BUILD-UP WITHIN THE STRUCTURE
DETERMINE INTERNAL BLAST FOR PARTIALLY VENTED STRUCTURES	TESTS COMPL & REPORT IN PREP. RESULTS WILL INDICATE VARIATION OF GAS PRESSURE VS VENTING AREA/STRUCTURE VOLUME/EXPLOSIVE WGT
DETERMINE EFFECTS OF MATL FRANGIBILITY ON VENTING	TEST PLAN COMPL AND TESTS IN PROGRESS – TO BE COMPL FY73

FIG 8

WEAPONS EFFECTS

EVALUATION OF LEAKAGE PRESSURES PRODUCED BY EXPLOSIONS IN FULLY OR PARTLY VENTED CUBICLES

PURPOSE	STATUS
ESTAB LEAKAGE PRESSURES FROM FULLY VENTED CUBICLES	● BELOW GROUND STRUCTURE TESTS COMPL & REPORT IN PREPARATION. RESULTS WILL INDICATE VARIATION OF PRESSURES ON THE GROUND WITH DISTANCE AS A FUNCTION OF CHARGE WGT AND CUBICLE DIM ● ABOVE GROUND STRUCTURE TEST HAS BEEN INITIATED
ESTAB LEAKAGE PRESSURES FROM PARTLY VENTED STRUCTURES	TESTS COMPL & REPORT IN PROGRESS.RESULTS WILL INDICATE VARIATION OF PRESSURES (ON THE GROUND) WITH DISTANCE AS A FUNCTION CHARGE WGT, VENTING AREA & STRUCTURE VOL
EFFECTS ON LEAKAGE PRESSURES PRODUCED BY FRANGIBILITY	TEST PLAN COMPL & TESTS IN PROGRESS.TO BE COMPL FY73

FIG 9

WEAPONS EFFECTS

EVALUATION OF DEBRIS EFFECTS DUE TO EXPLOSIONS

PURPOSE	STATUS
CLOSE-IN DEBRIS EFFECTS	● INITIAL TEST SERIES COMPL & REPORT BEING FINALIZED. RESULTS INDICATE VELOCITIES OF LARGE PIECES OF DEBRIS (SIMULATING EQUIPT, MOTORS, STL FRAMES, ETC) WILL ACHIEVE VEL UP TO 200 FPS FOR CHARGE WGT IN THE ORDER OF 20 LBS OR LESS ● PLANS FOR ADDITIONAL TESTING IS BEING DEVELOPED
FAR-RANGE DEBRIS EFFECTS	LITERATURE SEARCH BEING INITIATED TO DETERMINE DEBRIS PRODUCED AT LOCATION DISPLACED FROM AN EXPLOSION

FIG 10

TEST PROGRAM TO SUPPLEMENT TM5-1300

STRUCTURE RESPONSE

PURPOSE	STATUS
STRL RESPONSE OF R C	DVL PLAN FOR TEST OF PRE AND POST TENSION, LACED R C ELEMENTS AND STRUCTURE – IN PROGRESS DVL TEST PLAN FOR DETERMINING DESIGN CRITERIA FOR R C SHEAR WALLS – TO BE INITIATED
STRL RESPONSE OF STRL STL	DVL DSGN CRITERIA FOR STRL RESPONSE OF STRL STL CLOSE-IN TO EXPLOSIONS – IN PROGRESS DSGN OF TEST PLAN OF STRL STL CELLS TO LIMIT BLAST EFFECTS, DEBRIS AND PRIMARY FRAGMENTS – IN PROGRESS DEV OF TEST PLAN TO DETERMINE DESIGN CRITERIA FOR STRL RESPONSE OF STRL STL AT LOW PRESS RANGE – TO BE INITIATED
STRL RESPONSE OF OTHER MATERIALS	DVL TEST PROGRAM TO DETERMINE THE STRL RESPONSE OF MATLS, OTHER THAN R C AND STRL STL FOR FAR-RANGE BLAST EFFECTS – TO BE INITIATED DVL TEST PLAN TO DETERMINE INTERACTION OF SHOCK AND FRAGMENT ATTENUATING MATL WITH R C AND/OR STRL STL PLANNED

FIG 11

TEST PROGRAM TO SUPPLEMENT TM5-1300 (CONT)

STRUCTURE RESPONSE

PURPOSE	STATUS
STRL MOTIONS	EVLTN OF STRL MOTIONS FROM TRANSIENT EFFECTS OF AIR INDUCED PRESSURE – PLANNED
STRL RESPONSE OF TEE BARRICADES	DSGN OF ALTERNATE TO EARTH FILLED T-BARR – IN PROGRESS TEST PLAN TO EVAL PRESENT ALLOWABLE EXPL CAPACITY OF EXISTING TEE BARR AND TO DVL MEANS FOR INCREASING PRESENT CAPACITY – IN PROGRESS
RESPONSE OF BELOW GRADE STRUCTURES	DVL TEST PLAN TO DETERMINE DSGN CRITERIA FOR DSGN OF BELOW GRADE STRUCTURE TO INTERNAL EXPLOSION – IN PROGRESS

FIG 12

PROGRAMS TO SUPPLEMENT & MODIFY AMCR 385-100 & TM5-1300

PREPARATION OF SUPPLEMENTS

PURPOSE	STATUS
PREP OF PRELIM DSGN CHARTS AND COST INFO FOR R C CUBICLES USED IN FACILITY PLANNING	REPORT CONTAINING PRELIM DSGN CHARTS TO DETERMINE THICK OF LACED R C WALLS AS A FUNCTION OF CUBICLE DIM AND CHRG WGT AND COST OF CONSTR INFO – COMPL. TO BE SUBMITTED TO DODESB FOR APPROVAL AS SUPPL TO TM5-1300
PREP OF SAFETY CONCEPTS FOR USE IN MODERNIZATION OF MUCOM INSTL	REPORT DESCRIBING NEW SAFETY REG TO BE INCORP IN THE DSGN OF MODERNIZED MUCOM INSTL – COMPL. TO BE SUBMITTED TO AMC AND DODESB AS A SUPPL TO AMCR 385-100
PREP OF DSGN CRITERIA FOR OVERTURNING AND SLIDING OF CUBICLE TYPE STRUCTURES	REPORT CONTAINING DSGN CHARTS TO DETERMINE OVERTURNING AND SLIDING OF CUBICLE TYPE STRUCTURES – IN PROGRESS

FIG 13

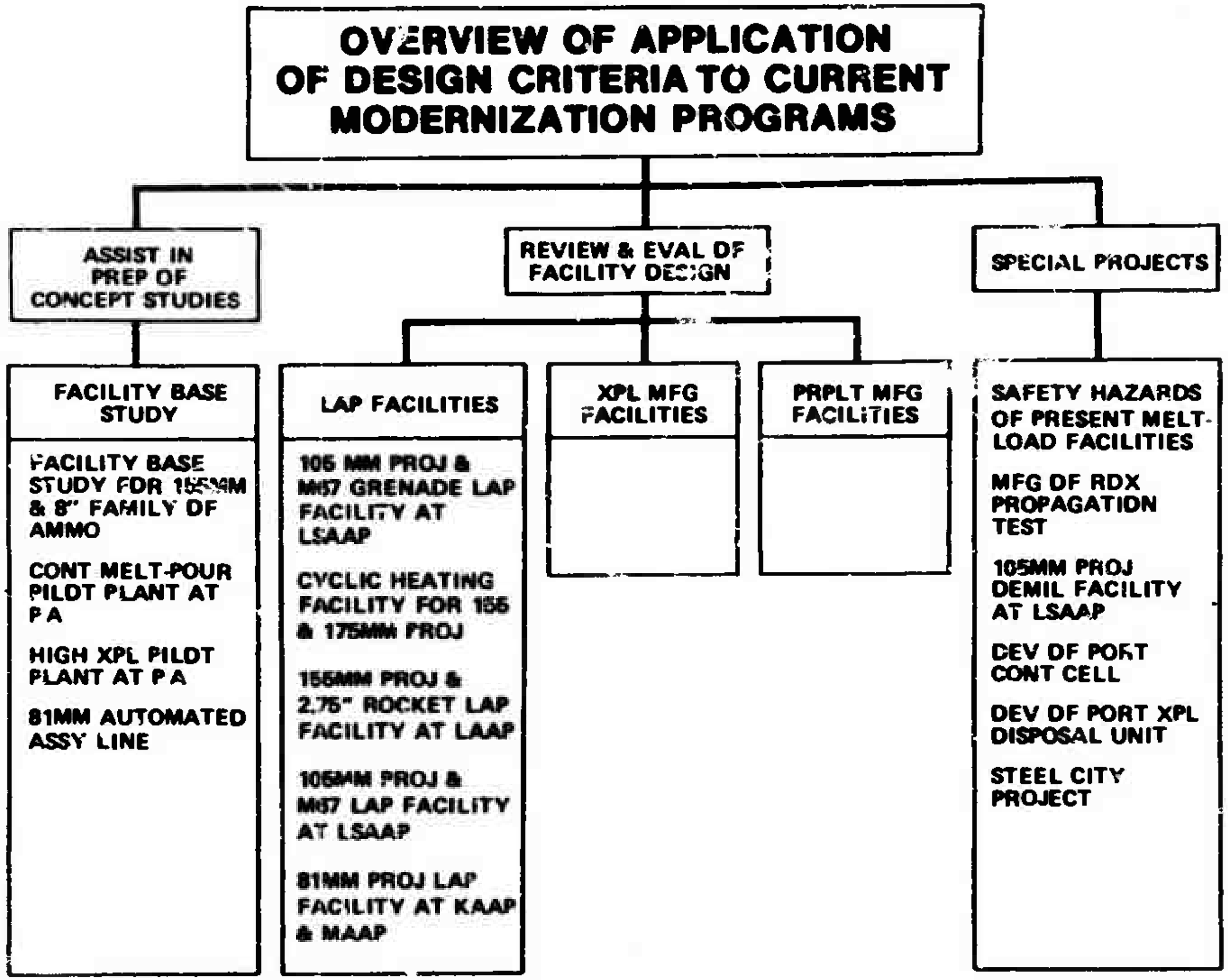

OVERVIEW OF APPLICATION OF DESIGN CRITERIA TO CURRENT MODERNIZATION PROGRAMS
ASSIST IN PREP OF CONCEPT STUDIES
REVIEW & EVAL OF FACILITY DESIGN
SPECIAL PROJECTS
FACILITY BASE STUDY
FACILITY BASE STUDY FOR 155MM & 8" FAMILY OF AMMO
CONT MELT-POUR PILOT PLANT AT PA
HIGH XPL PILOT PLANT AT PA
81MM AUTOMATED ASSY LINE
LAP FACILITIES
105 MM PROJ & M67 GRENADE LAP FACILITY AT LSAAP
CYCLIC HEATING FACILITY FOR 155 & 175MM PROJ
155MM PROJ & 2.75" ROCKET LAP FACILITY AT LAAP
105MM PROJ & M67 LAP FACILITY AT LSAAP
81MM PROJ LAP FACILITY AT KAAP & MAAP
XPL MFG FACILITIES
PRPLT MFG FACILITIES
SAFETY HAZARDS OF PRESENT MELT-LOAD FACILITIES
MFG OF RDX PROPAGATION TEST
105MM PROJ DEMIL FACILITY AT LSAAP
DEV OF PORT CONT CELL
DEV OF PORT XPL DISPOSAL UNIT
STEEL CITY PROJECT

FIG 14

APPLICATION OF DESIGN CRITERIA TO CURRENT MODERNIZATION PROGRAMS

ASSISTANCE IN PREPARATION OF CONCEPT STUDIES

TITLE	PURPOSE AND STATUS
FACILITY BASE STUDY ON FUTURE REQ FOR 155MM AND 8 IN FAMILY OF AMMUNITIONS	PREPARED CONCEPTUAL STUDIES ON LAYOUT OF LAP FACILITIES FOR 155MM AND 8 IN AMMO: • ESTABLISH METHOD FOR UTILIZATION OF SAFE DISTANCES • ESTABLISH COST DATA AND STRUCTURAL REQ VS EXPLOSIVE QUANTITY • PREPARE DESIGNS ON M106 AND M107 LINES; XM549 AND XM650 RAP LINES; COMPOSITE 8 IN AND 155MM HE & RAP LINE; AND SUPPORTING FUZE LINE. TASK 90% COMPLETE
CONTINUOUS MELT-POUR PILOT FACILITY AT PA	• PREPARED DSGN OF RC BARRIER FOR MELT-POUR PILOT PLANT AT PA (COMPLETED)
HE PILOT PLANT AT PA	• PERFORM FEASIBILITY STUDY ON CONTROL ROOM AND TESTING LABS FOR HE PILOT PLANT AT PA (COMPLETED)
81MM AUTOMATED ASSEMBLY LINE	• PREPARED CONCEPT STUDY INCLUDING DEVELOPMENT OF PROTECTIVE BARRIERS FOR HARDOUS STATIONS FOR 81MM LAP PLANT (COMPLETED)

FIG 15

APPLICATION OF DESIGN CRITERIA TO CURRENT MODERNIZATION PROGRAMS

REVIEW AND EVALUATION OF FACILITY OESIGN

LAP FACILITIES

TITLE	PURPOSE ANO STATUS
REVIEW AND COMPARISON OF PROPOSAL ON CONSTR OF NEW CYCLIC HEAT FACILITIES FOR LOADING 155MM AND 175MM COMP B SHELL	PERFORMEO DETAILEO EVLTN AND COMPARISON ON PROPOSED CYCLIC HEAT FACILITIES SUBMITTEO BY RAVENNA, IOWA AND LOUISIANA AAP. ENTAILS SAFETY EVLTN, FACILITY LAYOUT ANO COMPARISON OF ESTIMATED CONSTR COSTS–COMPL
155MM PROJECTILE LAP FACILITY (S-LINE) AT LAAP	ASSIST IN OEV OF MODERNIZEO LAP FACILITY FOR 155MM PROJECTILE (S-LINE) AT LAAP – IN PROCESS
105MM PROJECTILE LAP FACILITY AT LSAAP	ASSIST IN OEV OF MODERNIZED LAP FACILITY FOR 105MM PROJECTILES (E-LINE) AT LSAAP – IN PROCESS
81MM PROJECTILES LAP FACILITY AT KAAP	ASSIST IN DEV OF HAZARO CATEGORY 3 PROTECTIVE CELL IN ASSEMBLY AREA OF LAP FACILITY FOR 81MM PROJECTILE AT KAAP – IN PROCESS
81MM PROJECTILE LAP FACILITY AT MAAP	ASSIST IN OEV OF MODERNIZED LAP FACILITY FOR 81MM PROJECTILE AT MAAP – IN PROCESS
[illegible]CKET LAP F[illegible]	ASSIST IN DEV OF MODERNIZED LAP FACILITY FOR 2.75 INCH ROCKET AT LAAP – COMPL

FIG 16

APPLICATION OF DESIGN CRITERIA TO CURRENT MODERNIZATION PROGRAMS

SPECIAL PROJECTS

TITLE	PURPOSE & STATUS
IMPROVE SAFETY IN MELT LOAD OPERATIONS ESTAB PROPAGATION IN RDX/HMX PRODUCTION AT HAAP	• ANALYZING S-LINE AT LAAP (TYP FACILITY) TO IDENTIFY HAZARDS • COMPL INITIAL TESTS TO DETERMINE PROPAGATION BETWEEN TANKS OF B&D BLDG – INTERIM REPORT BEING PREPARED • COMPL TNT EQUIV TESTS – REPORT BEING PREPARED • TEST PLAN FOR SECONDARY FRAGMENT IMPACT RDX SLURRY COMPL. TESTS TO BE INITIATED SHORTLY
105MM PROJ DEMIL FACILITY AT LSAAP	DVL PROT STRUCTURE CRIT FOR 105MM PROJ DEMIL FACILITY AT LSAAP – IN PROGRESS
PORTABLE CONTAINMENT CELL (EDGEWOOD ARSENAL)	DVL PORT CONTAINMENT CELL FOR ON-SITE DISPOSAL OF TOXIC-XPL WEAPONS. INVOLVES DSGN, FAB OF PROTOTYPE STRUCTURE, TESTING, EVAL OF TEST RESULT AND FAB OF PILOT CELL. AT PRESENT, PROTOTYPE CELL BEING FAB

FIG 17

APPLICATION OF DESIGN TO CRITERIA TO CURRENT MODERNIZATION PROGRAMS (CONT)

SPECIAL PROJECTS

TITLE	PURPOSE & STATUS
STEEL CITY PROJECT	DVL SITE PLANS, STRL CONFIG AND COST ESTIMATES FOR FOLLOWING FACILITIES • DUAL-PROJECTILE LAP FACILITY, MEDIUM SIZE PROJECTILES-105MM • MULTI-PROJECTILE LAP FACILITY, MAJOR SIZE PROJECTILES-155MM, 175MM & 8 IN • BAG LOADING FACILITIES FOR 105MM, 155MM, 8 IN PROJECTILES
PORT XPL DISPOSAL UNIT	RESEARCH & CONCEPTUAL DSGN OF PORT XPL DISPOSAL UNIT – 90% COMPL

FIG 18

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SAFETY ENGINEERING IN SUPPORT OF AMMUNITION PLANTS

SUMMARY

- DEVELOPED NEW METHOD FOR BLAST RESISTANT CONSTR VALIDATED USE OF SCALE MODEL TESTING & EVALUATED CAPACITIES OF NEW PROTECTIVE CONSTR
- PREPARED SAFETY DSGN MANUAL FOR "STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS" (TM5-1300)
- PREPARED PRELIM DSGN AND COST INFO FOR R. C. CUBICLES USED IN FACILITY PLANNING
- PERFORMING ANALYTICAL & EXPERIMENTAL WORK TO BROADEN THE SCOPES OF TM5-1300, AMCR385-100 & HAZARD CLASS BULLETIN TB700-2
- PERFORMING TNT EQUIV TESTS OF XPLS, PRPLTS, PYRO & XPL END-ITEMS. ESTAB TNT EQUIV OF BLACK POWDER-FINAL PRODUCT & IN-PROCESS MATERIALS
- PROVIDING ENGRG ASSISTANCE TO MUCOM FACILITIES TOWARD THEIR PREPARATION OF DSGN CRITERIA & CONCEPTS FOR MODERNIZED FACILITIES

FIG 19

PLANT MODERNIZATION AT VOLUNTEER ARMY AMMUNITION PLANT

LTC E. J. Bourgeois, Jr., USA
Volunteer Army Ammunition Plant
Chattanooga, Tennessee

Good afternoon ladies and gentlemen. My topic today is Plant Modernization at Volunteer Army Ammunition Plant in Chattanooga, Tennessee. I want to point out some safety considerations that went into the modernization planning and the safety benefits derived from modernization, in addition, I will expound on the economic and pollution abatement benefits from the modernization. (Figure 1)

To orient us, I will start with a brief background on the operation and history of the Volunteer Army Ammunition Plant, followed by description of the old and new facilities and a comparison of the two.

Volunteer produces trinitrotoluene, better known as TNT. TNT has been one of our most important military explosives for some time. During World War I, economics kept the United States from using it extensively due to the limited supply of toluene, which is the primary ingredient. This situation was remedied when extraction of toluene as a by-product from Petroleum Industries was made readily available. TNT can now be produced economically and in vast quantities. We at VAAP take great pride in the fact that we produce approximately one-third of the Free World's TNT.

HISTORY

Our plant was originally established as the Volunteer Ordnance Works by War Department in October 1941. (Figure 2)

Approximately 8,600 acres were purchased in Hamilton County, Tennessee for the construction of 16 TNT lines capable of producing approximately 1,000,000 pounds per day. The plant was operated at maximum effort until August 1945, producing over 800 million pounds of high explosives. With the cessation of hostilities in late 1945, the plant was placed in a standby status until it was reactivated in support of the Korean conflict. Production was started in June 1953 and continued until April 1957, during which time 300 million pounds of explosives were produced.

In the fall of 1965, the plant was reactivated in support of Southeast Asia. Over 1.5 billion pounds of TNT have been made to date. This is considerably higher than the combined total for World War II and the Korean conflict.

Prior to the reactivation in 1965, it was anticipated that the antiquated plant and equipment would provoke criticism from both the Air and Water Pollution standpoints. (Figure 3) This opinion was based on a gradual population buildup around the plant through the years and increased public resentment to pollution in general. Recent annexations, by city, have extended city limits to plant boundary. The anticipated complaints became a reality in 1967 when Chattanooga was designated the third most polluted city in the United States. It was at this time, that plans were first made for the modernization program at Volunteer for both pollution abatement economic benefits.

MODERNIZATION

A 12-year Master Plan to completely modernize Volunteer was developed (Figure 4). All facilities were designed to comply with applicable safety regulations; i.e., no safety waivers were to be allowed. The cost of the Master Plan totaled approximately 149 million dollars. Fortunately, the economies, as well as improved safety, justified this expenditure.

The Department of the Army and the operating contractor put a great deal of effort into designing a completely new plant which encompassed the latest technology in the manufacture of TNT and assorted acids. Safety in design was incorporated into each facet of operation from the beginning of the project. Three cardinal safety principles were observed in all planning for the future; they were: (Figure 5)

1. Staff each operation with the minimum of workers.

2. Permit only those quantities of explosives in process essential to meet production rates.

3. Disperse or barricade buildings whereby a detonation will not destroy the entire line by propagating from building to building. Of course, we also considered reduction of pollution and cost of operation.

Application of modern chemical processing technology which allows for continuous processes and remote control embodied the first two principles. The continuous Canadian Industries Limited (CIL) process, our new method of producing TNT, controlled by a remote direct digital control system incorporates all three principles.

The new acid plants are controlled from central control rooms with modern process control instrumentation. The new TNT lines will use a pneumatic conveying system/TNT bulk handling facility to automate the packaging and handling of TNT. This will be discussed in a few moments.

In all of these units, the quantity of explosive and hazardous material in process and the number of personnel directly exposed to hazardous conditions are minimized.

Let us now turn our attention to the acid facilities which produce most of the acids we use in the manufacture of TNT.

(Figure 6) The old weak nitric acid, Ammonia Oxidation Plant Facility (AOP), has produced 60% nitric acid since 1942 (Figure 7) and is still operating today. It is being replaced by a much more modernized facility which is capable of producing 220 tons of 60% acid per day. The advantages of the new plant over the old plant are (Figure 8):

1. A 60 percent reduction in operating personnel.
2. Remote control.
3. Fail Safe Instruments.
4. A 50 percent reduction in operating costs.
5. A 96 percent reduction in pollution emissions.

It should be pointed out that reduction of pollutants emitted improves the safety of the plant by reducing the exposure of operating personnel to noxious and sometimes toxic pollutants. It may also be noted here that there is a marked reduction of noise in the new facilities.

(Figure 9) In the old strong nitric acid facilities, 98% nitric acid is produced by concentrating weak (60%) nitric acid. This is accomplished by using sulfuric acid to dehydrate the weak nitric acid. The spent sulfuric acid (Figure 10) is then recycled in the Sulfuric Acid Concentration (SAC) unit for re-use. Both facilities have also been operating since 1942, and both of them will be replaced by our new Direct Strong Nitric (DSN) Figure 11) unit which produces 96% nitric acid. The advantages of this new unit are: (Figure 12)

1. A 25 percent reduction in operating personnel.
2. Remote control.
3. Fail Safe Instruments.
4. A 48 percent reduction in operating costs.
5. A 90 percent reduction in pollution emissions.

(Figure 13) Our old Oleum Plant produces our fuming sulfuric acid. The new Sulfuric Acid Regeneration (SAR) unit (Figure 14) which replaces the old facility, has the capability to produce about twice as much oleum per day as the old plant (Figure 15). Other advantages of the new SAR plant are:

1. A 40 percent reduction in operating personnel.
2. Remote control.
3. Fail Safe Instruments.
4. A 65 percent reduction in operating costs.
5. A 97 percent reduction in pollution emissions.

The new acid plants are located in the area of what used to be our burning grounds. Their installation meant that we had to develop a new burning ground (Figure 16). We took this opportunity to construct one of the most modern facilities of its kind in the country. It was designed with safety in mind and contains approximately 76 acres (Figure 17). It is used to dispose of waste explosives and to flash both scrap and reclaimable materials on a 24-hour basis. We have MCA projects programmed to install pollution-free incinerators in the future.

Realizing of course, the acids previously discussed are used in the manufacture of TNT, let us now look at our old batch TNT process (Figure 18). Remember that TNT is simply toluene that has been nitrated three times. Toluene is nitrated in the mono house to produce mono-oil (mono-nitro-toluene). Mono-oil goes to the bi house where it is again nitrated to produce bi-oil (bi-nitro-toluene). The bi-oil is transferred to a tri house where the third nitration takes place to produce crude TNT. This crude TNT is purified in the wash house with a sellite wash. The purified TNT is flaked and packed in 55-pound boxes and shipped or stored. Spent acids and fumes produced in the nitration processes are recovered in the acid and fume recoveries.

Let's take a closer look at the old facilities (Figures 19, 20, 21, 22, 23 and 24). When the crude TNT is purified, the impurities are diluted in water (Figure 25). This water becomes "Red Water". It contains 8% solids of nitro-bodies. To eliminate the pollution problem, Red Water is reduced to 35% solid solution by evaporation (Figure 26) and then sold to the paper industry. Previously it was incinerated. A recycling method for "Red Water" is currently being developed.

Replacing most of these facilities are the new CIL continuous TNT lines. (Figure 27) Four buildings - the mono house, bi house, tri house and wash house will be replaced by two buildings, the nitration and purification building and a finishing building. Here is a view of the first CIL under construction, to be completed in June 73 (Figure 28).

Remember I said earlier that in the new CIL lines we would use a pneumatic conveyor. Volunteer has developed a prototype system which is currently undergoing testing (Figure 29). Plans are to include the system in our new lines. It will move the TNT from the finishing building to the packaging building through a 6" pipeline by means of a vacuum. Approximately 1000 ft. of transfer pipe has been installed and tested to simulate field conditions at a loading plant. Naturally, safety has played an important role in developing this prototype. The use of 3,650 pound aluminum tote bins (Figure 30) is also a part of the concept. It will eliminate the labor cost in handling 55 pound cartons. The benefits derived from using the larger bins can easily be recognized when you compare their size. (Figure 31) Here is a view of loading station and one of unloading (invertor) at load facility (Figure 32).

Some of the advantages of the new TNT lines are: (Figure 33)

1. A 47 percent reduction in personnel.
2. Remote control.
3. Computer operated.
4. A 75 percent reduction of explosives in process (44,000 vs 14,000 per line).
5. A 42 percent reduction in operating costs.
6. A 99 percent reduction in pollution emissions.

An initial economic comparison of the old versus the new facilities demonstrated a cost reduction of approximately $12 per ton for 60 percent nitric acid (or 50%), a $27 per ton for 98 percent nitric acid (or 48%) and a $11 per ton for oleum (or 65%) (Figure 34). These acid cost reductions plus savings in the TNT lines, produce a net cost reduction of approximately $112 per ton of TNT (or 42%).

Also the advantages of each of the new facilities, in relation to pollution and personnel reductions, creates an overall average of approximately 95% reduction in pollution and overall reduction of personnel of about 43% (Figure 35).

Among the areas where we feel Volunteer has made unique contributions to the Department of the Army's modernization program, are the direct strong nitric acid plant which has been installed to replace the old NAC-SAC units; Computer simulation has been used to model the continuous CIL TNT Process to obtain better insights; remote control of the CIL TNT process will be accomplished by installing a direct digital control system; pneumatic conveying and other forms of bulk handling have been designed and prototyped to replace the old manual handling of 50 or 55 pound boxes of TNT. In addition to reducing the costs of handling, this substantially improves safety by reducing personnel exposure to TNT. Red Water produced by the sellite purification wash of crude TNT has been marketed to the paper industry, thereby eliminating the disposal problem and gaining some economic benefit. Of course, much consideration must be given to ICI America (old Atlas Chemical Company) our operating contractor, for these developments.

Some of the lessons we have learned at Volunteer from our modernization program are: planning is critical; an adequate engineering staff is important; team work is essential; knowledge of the latest technology and safety considerations is extremely beneficial; detailed review of all stages of plans and specifications should include formal emphasis on safety considerations; inspection of the construction site is also necessary.

To summarize, we at Volunteer Army Ammunition Plant are proud of our modernization accomplishments dating from the positive approach taken in

1967 when modernization was first proposed. Volunteer was the first Army Ammunition Plant to develop and recommend complete modernization plans justified by decreased costs, reduced pollution emissions and increased safety. It is our firm belief that a carefully planned and properly engineered plant will have safety incorporated into each minute detail.

Thank you. Now if anyone has any questions, I will be glad to answer them.

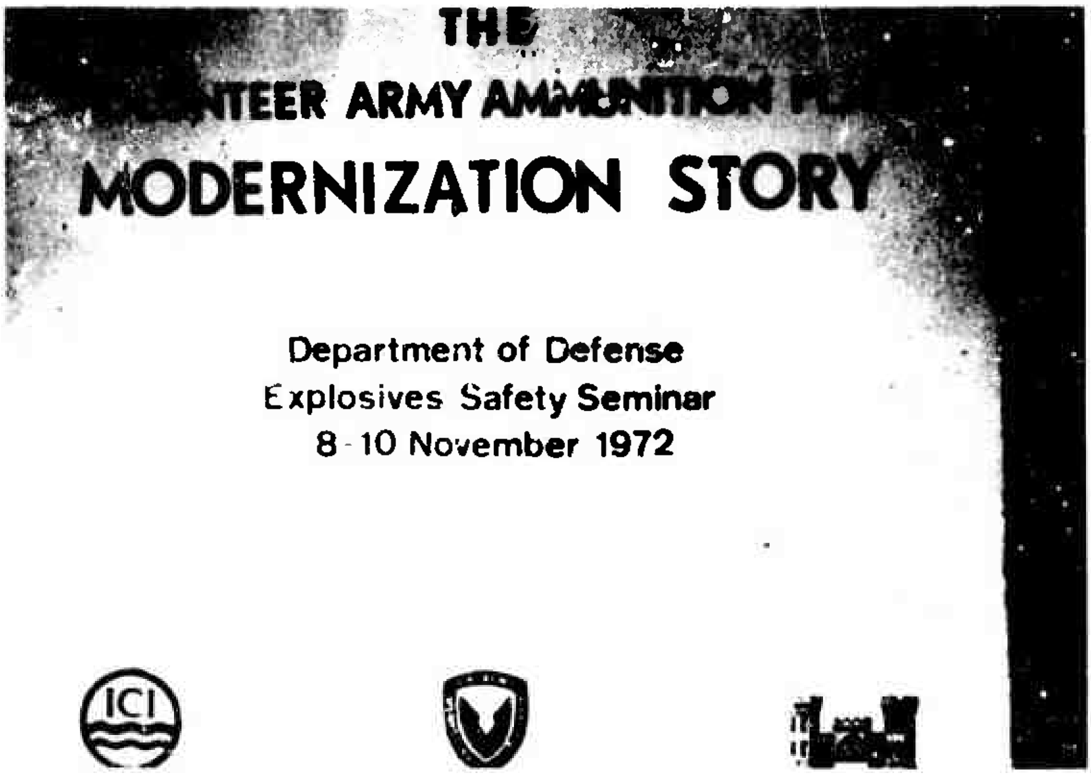

THE
ARMY
MODERNIZATION STORY
Department of Defense
Explosives Safety Seminar
8-10 November 1972
ICI

Figure 1

Figure 2

Figure 3

TWELVE YEAR MASTER PLAN

INSTALLATION: VOLUNTEER

PROJECT TITLE	70	71	72	73	74	75	76	77	78	79	80	81	TOTAL
Mod 3 TNT Lines, 1st Inc	20.8												20.9
Const 800 T/D Oleum Plt w/SAR Unit 1	10.2												10.2
Const 280 T/D AOP	5.2												5.2
Const 280 T/D DSN Plt	10.4												10.4
Mod 6 TNT Lines, 2d Inc		24.5											24.5
Mod TNT Bulk Handling				7.1									7.1
Const New Dispensary					0.4								0.4
Const New Acid Laboratory					0.3								0.3
Const 800 T/D Oleum Plt w/SAR, Unit 2						16.0							16.0
Combined Maint Shops						2.2							2.2
Packaged Boiler Plant									0.8				0.8
Mod 4 TNT Lines, 3d Inc									42.0				42.0
Const New Admin Bldg									2.0				2.0
Mod Red Water Fac										7.0			7.0
	40.7	24.5		7.1	0.7	18.2			44.8	7.0			149.0

[illegible]

Figure 4

SAFETY PRINCIPLES

MINIMUM PERSONNEL EXPOSURE

MINIMUM AMOUNT OF EXPLOSIVES IN PROCESS

MAXIMUM PROTECTION

DISPERSAL / BARRICADE

Figure 5

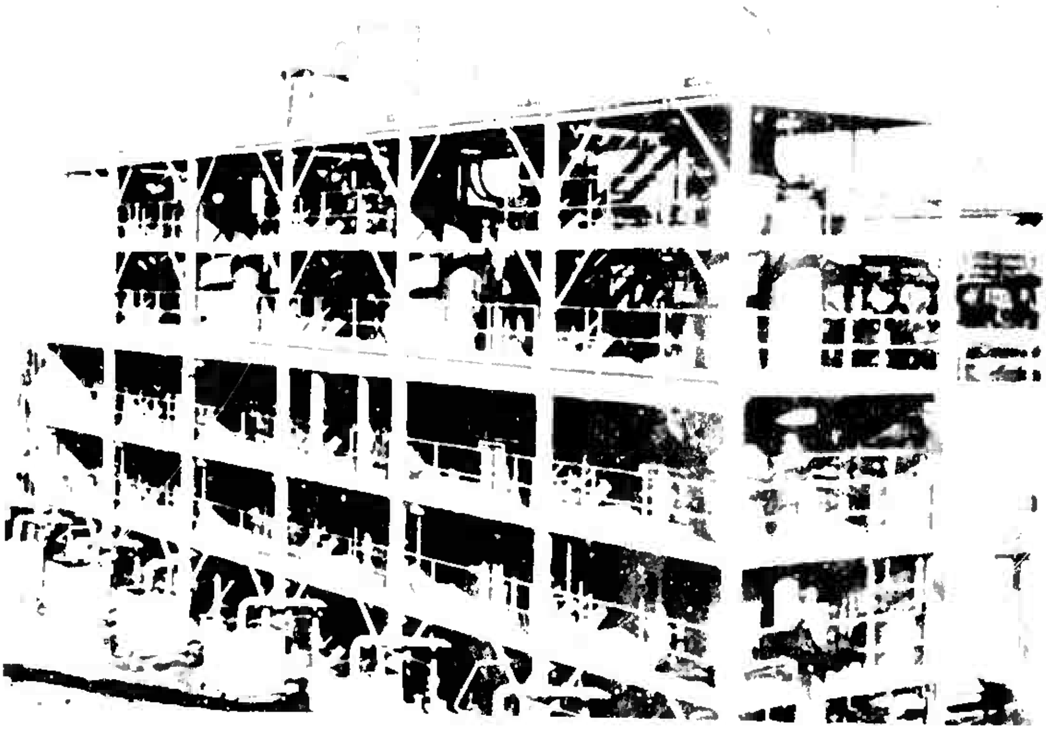


Figure 6

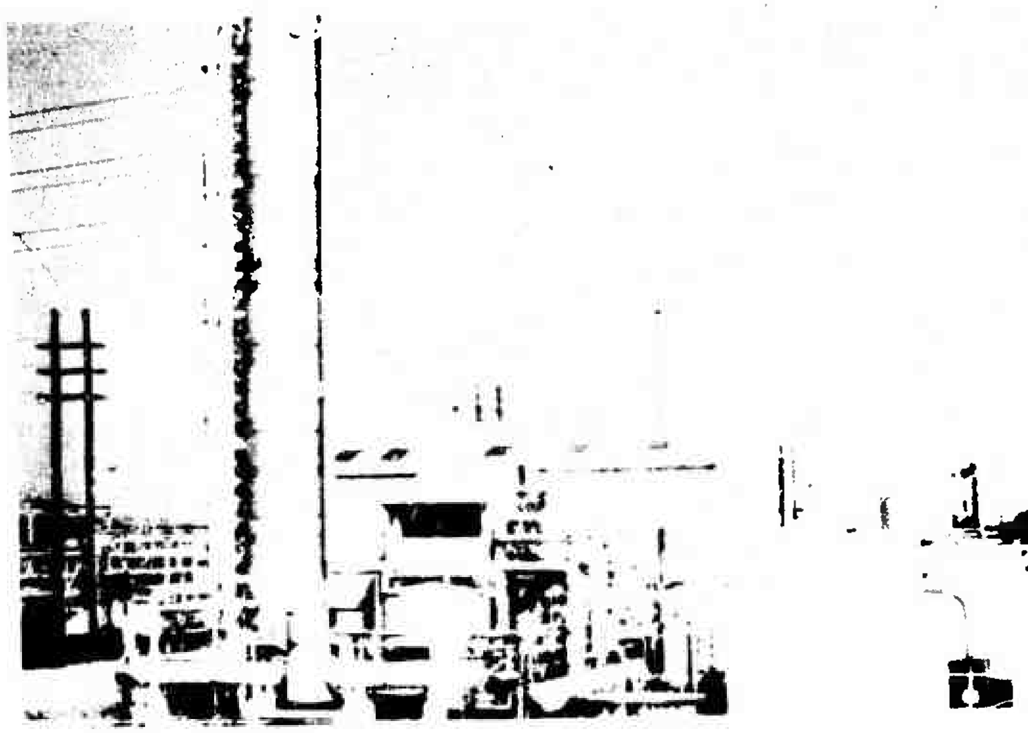


Figure 7

PRIMARY ADVANTAGES
OF
NEW WEAK NITRIC ACID PLANT

60% REDUCTION IN PERSONNEL

REMOTE CONTROL

FAIL SAFE INSTRUMENTATION

50% REDUCTION IN OPERATING COSTS

96% REDUCTION IN POLLUTION EMISSIONS

Figure 8

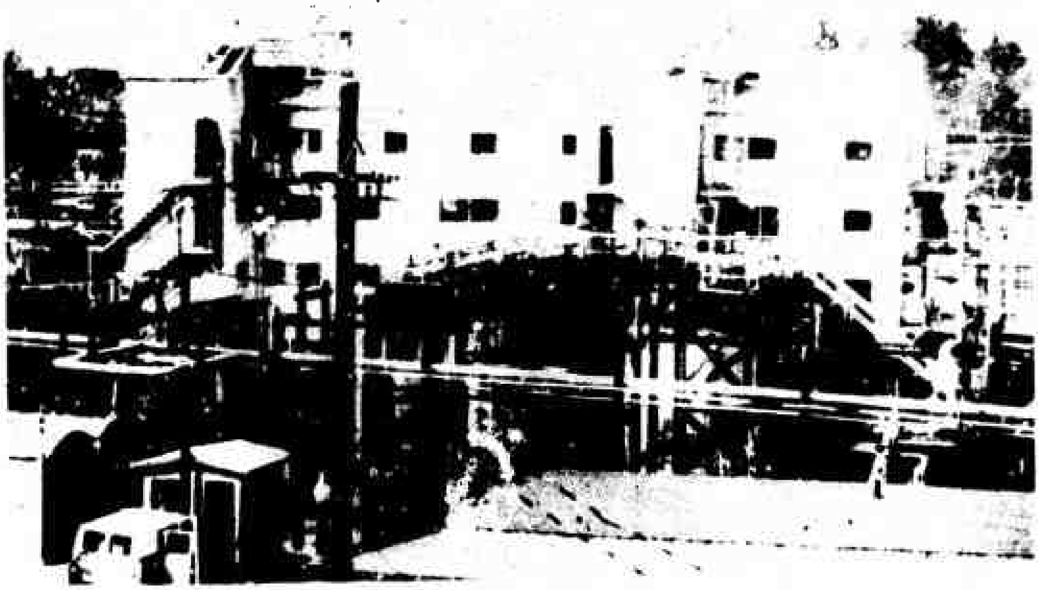


Figure 9

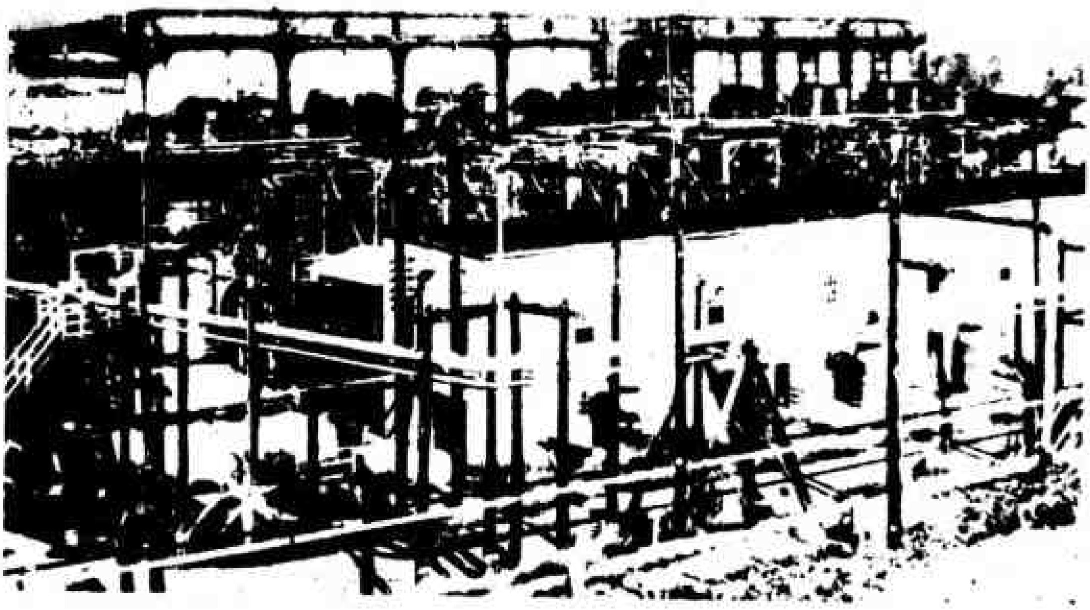


Figure 10

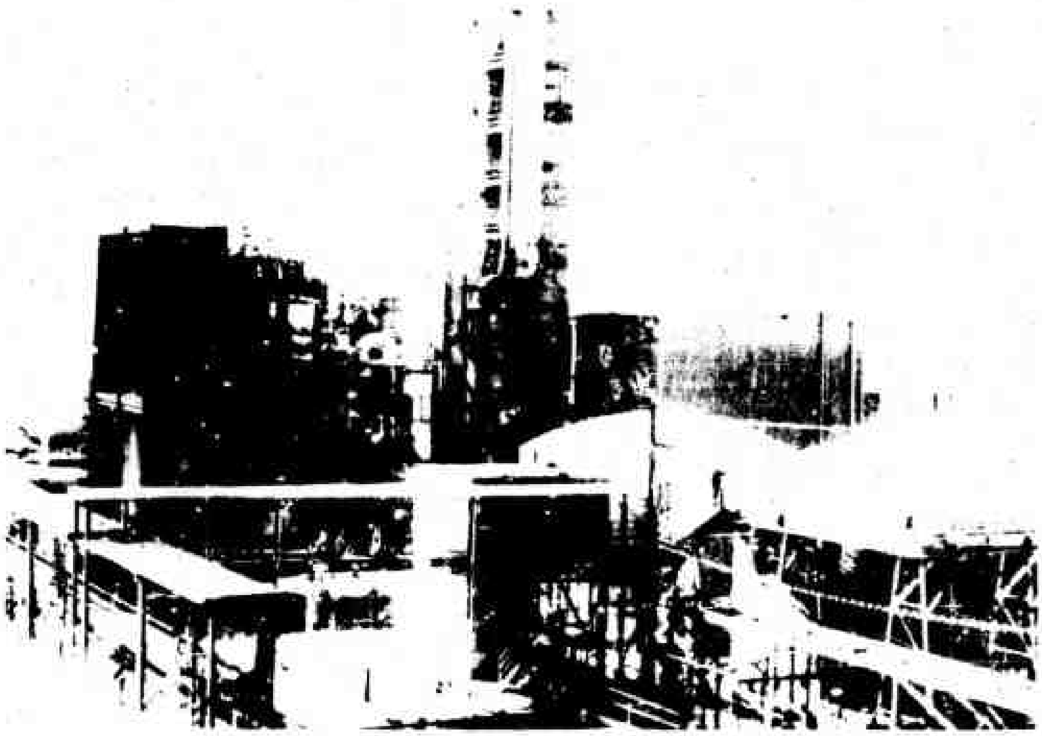


Figure 11

PRIMARY ADVANTAGES

OF

NEW STRONG NITRIC ACID PLANT

25% REDUCTION IN PERSONNEL

REMOTE CONTROL

FAIL SAFE INSTRUMENTATION

48% REDUCTION IN OPERATING COSTS

90% REDUCTION IN POLLUTION EMISSIONS

Figure 12

Figure 15

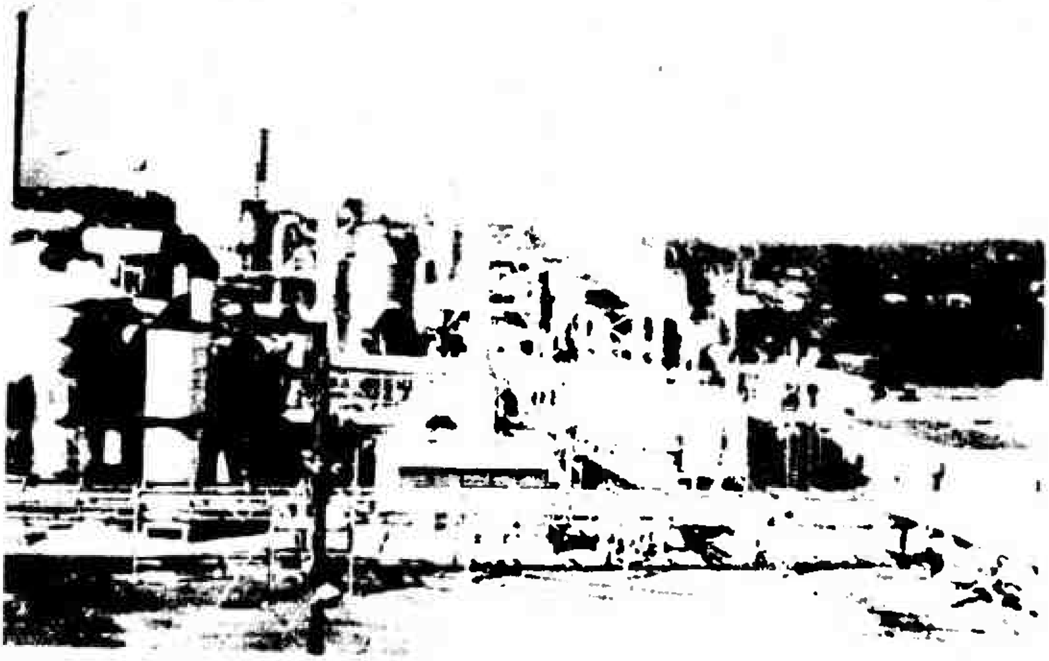


Figure 14

PRIMARY ADVANTAGES
OF
NEW OLEUM PLANT

40% REDUCTION IN PERSONNEL

REMOTE CONTROL

FAIL SAFE INSTRUMENTATION

65% REDUCTION IN OPERATING COSTS

97% REDUCTION IN POLLUTION EMISSIONS

Figure 15

Figure 16

Figure 17

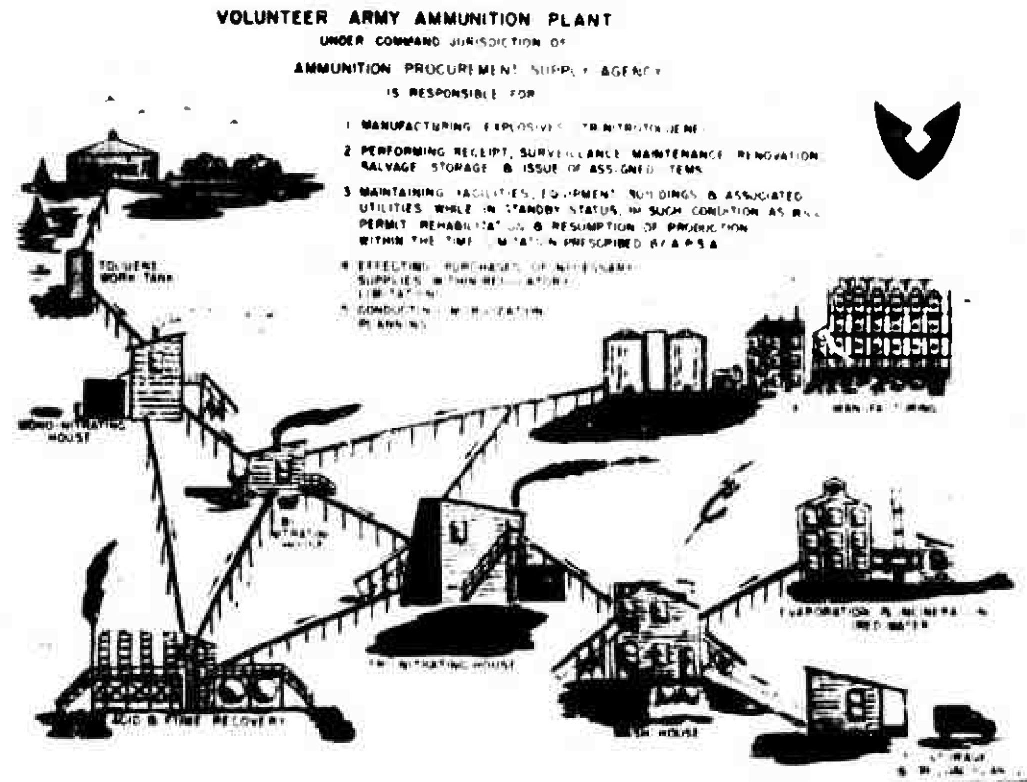

VOLUNTEER ARMY AMMUNITION PLANT
UNDER COMMAND
AMMUNITION PROCUREMENT
IS RESPONSIBLE FOR
TOLUENE WORK TANK
MONO-NITRATING HOUSE

Figure 18

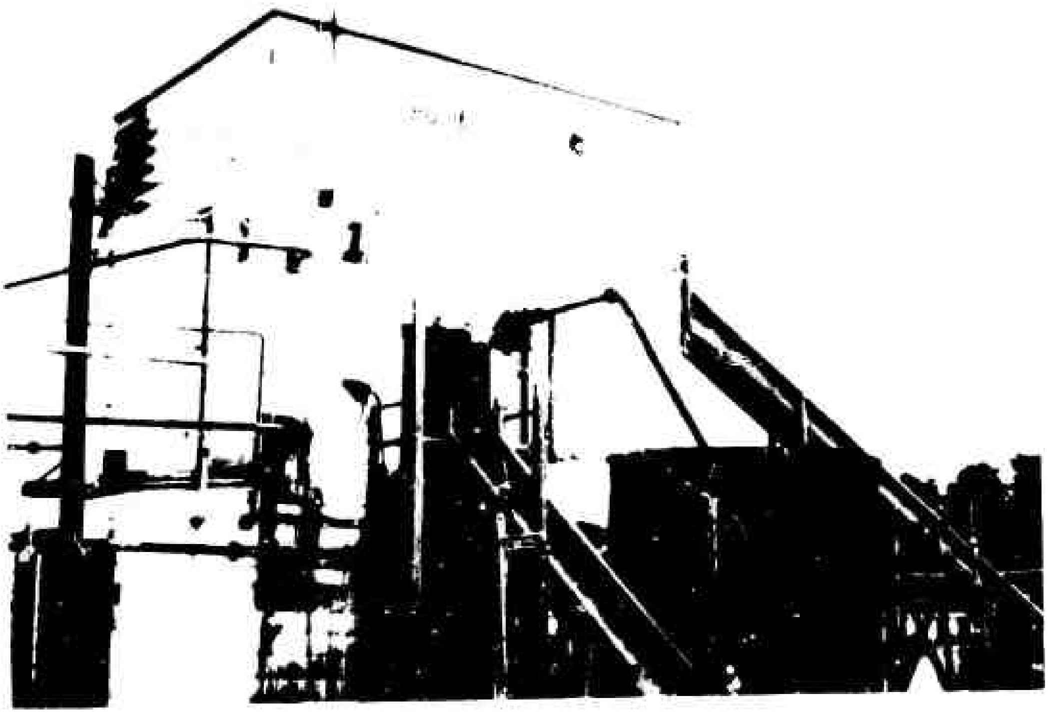


Figure 19

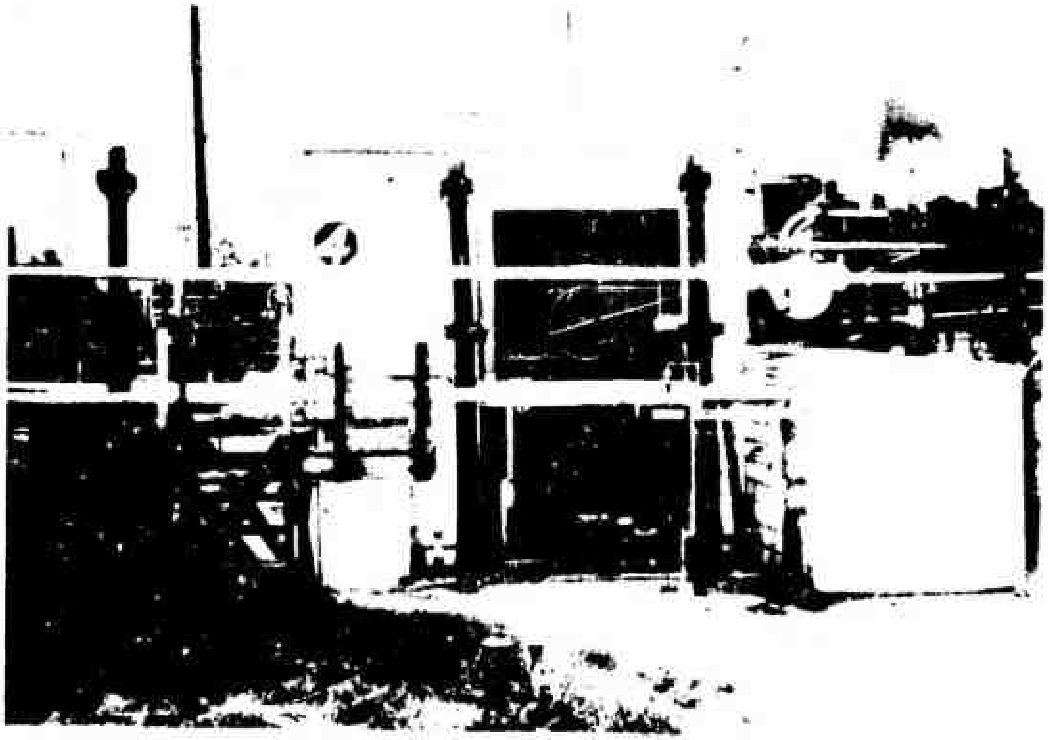
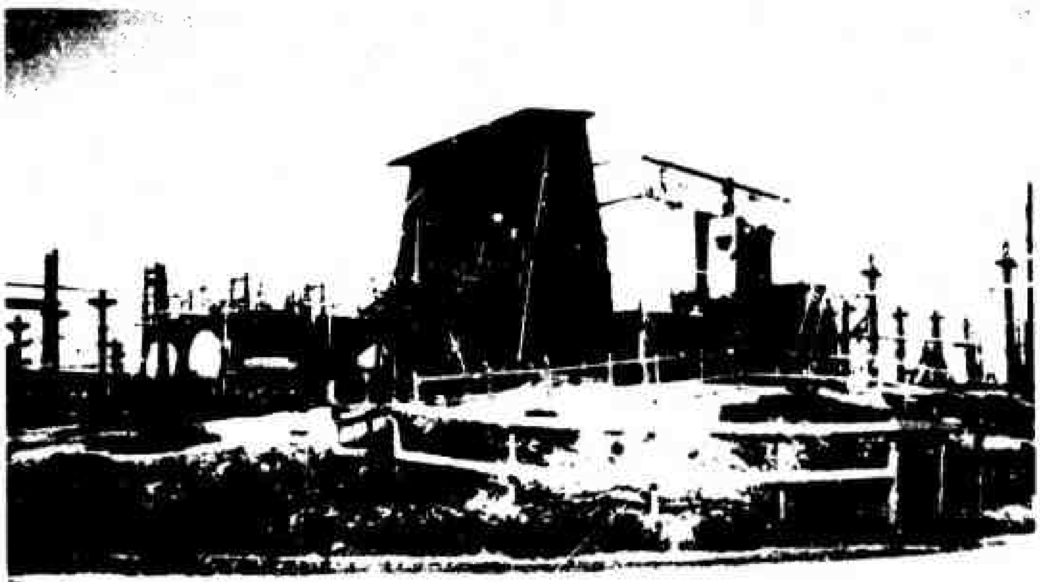


Figure 20



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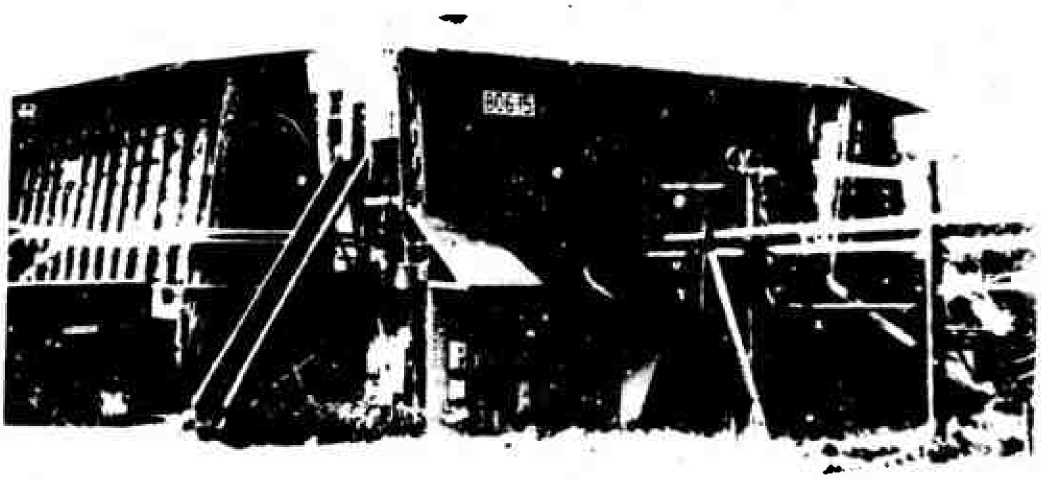
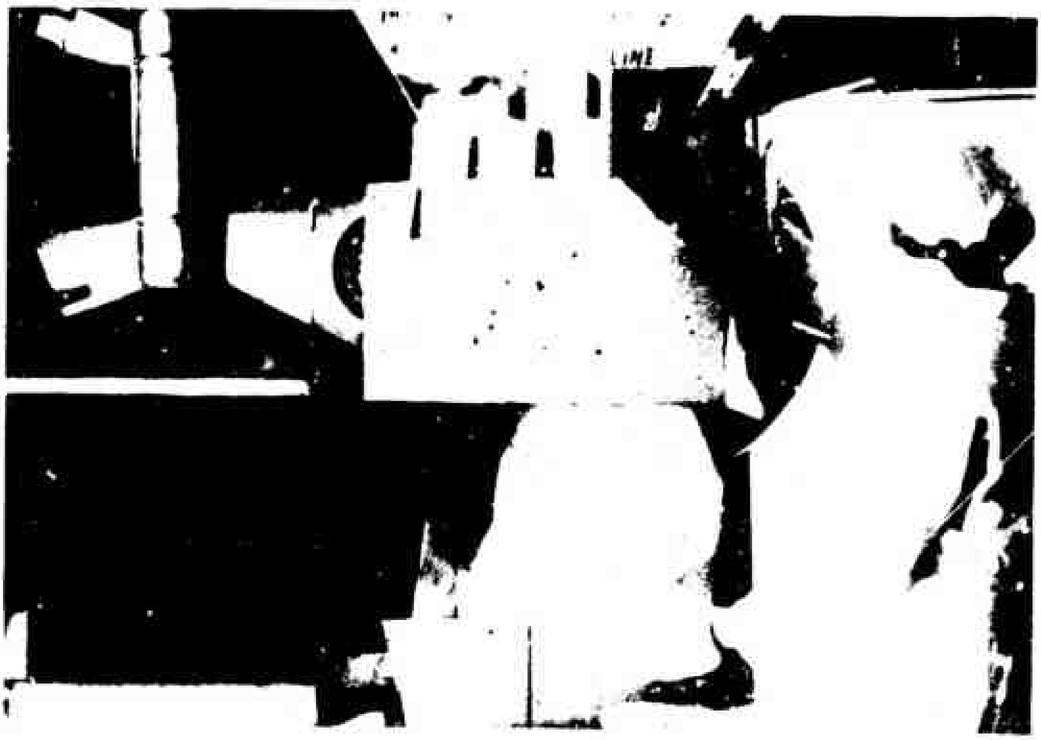


Figure 22



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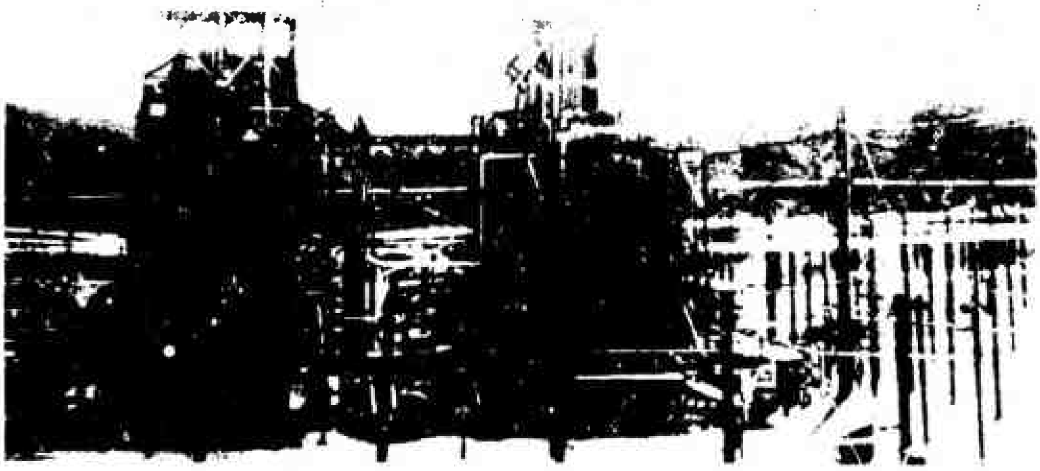


Figure 24

Figure 25

Figure 26

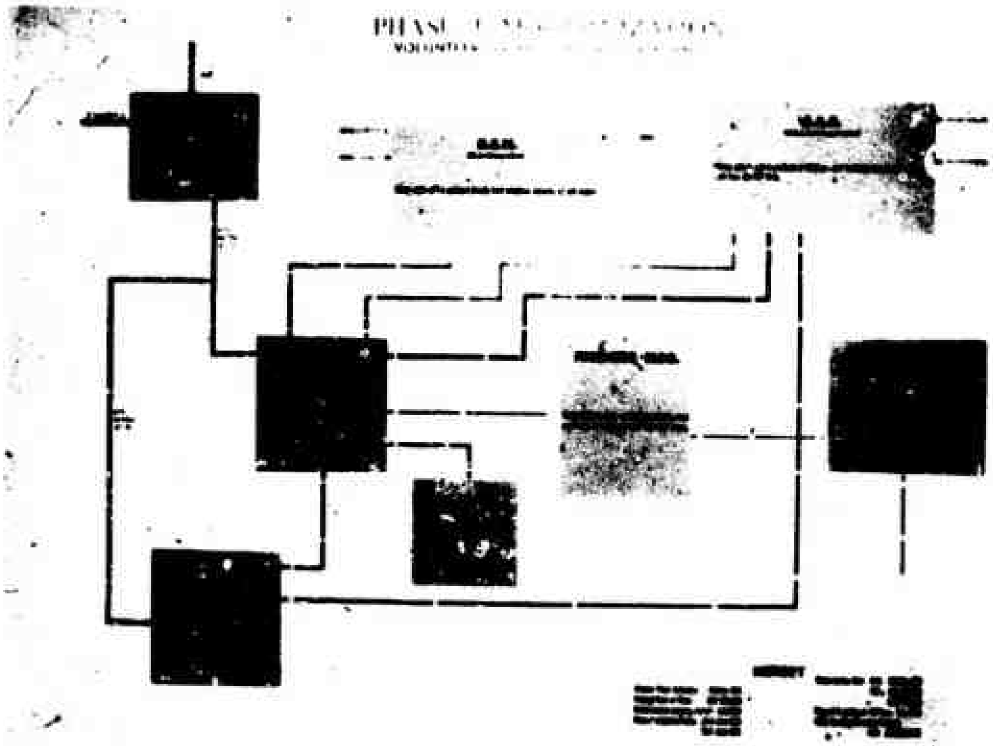


Figure 27

Figure 28

Figure 29

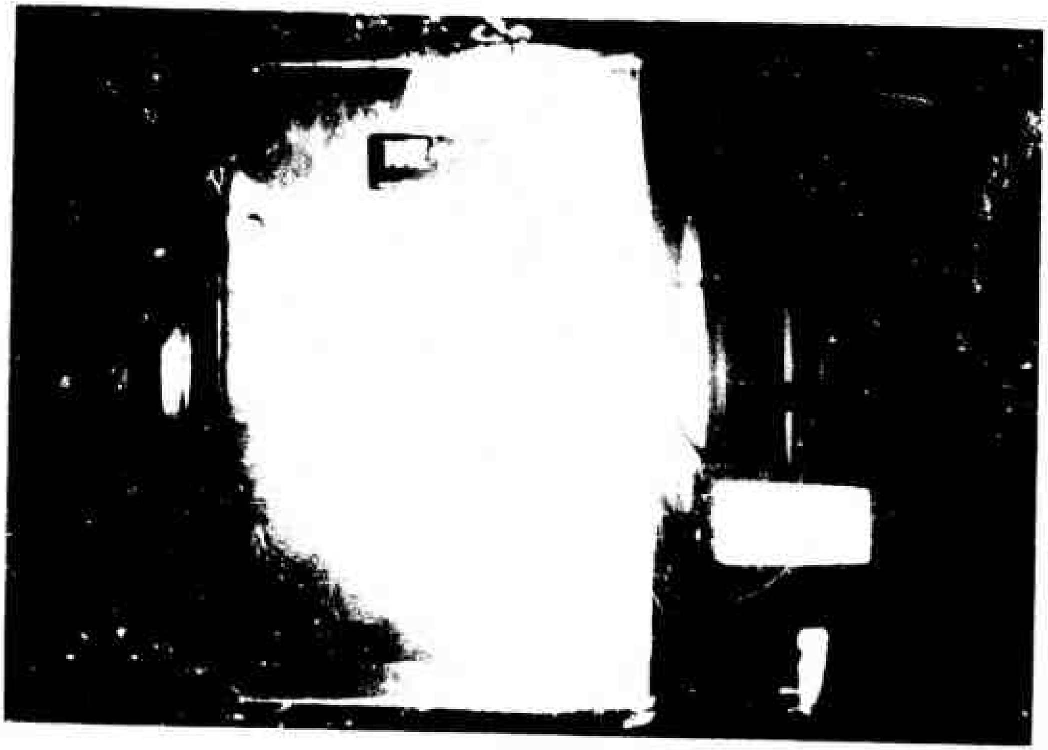


Figure 30

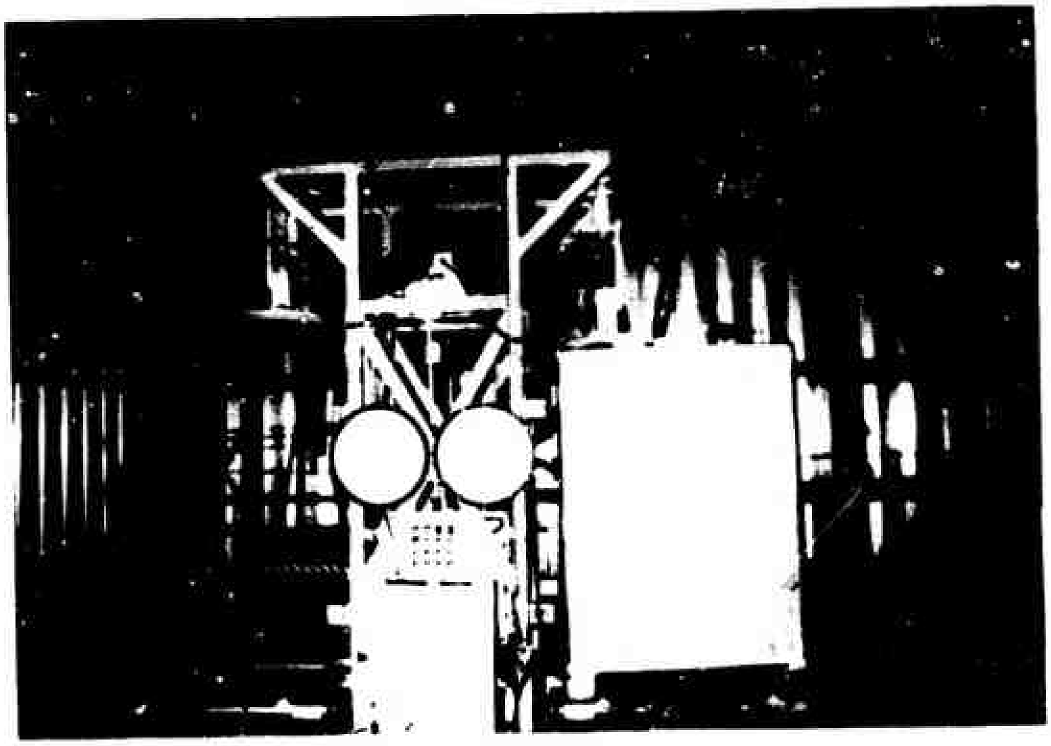


Figure 31

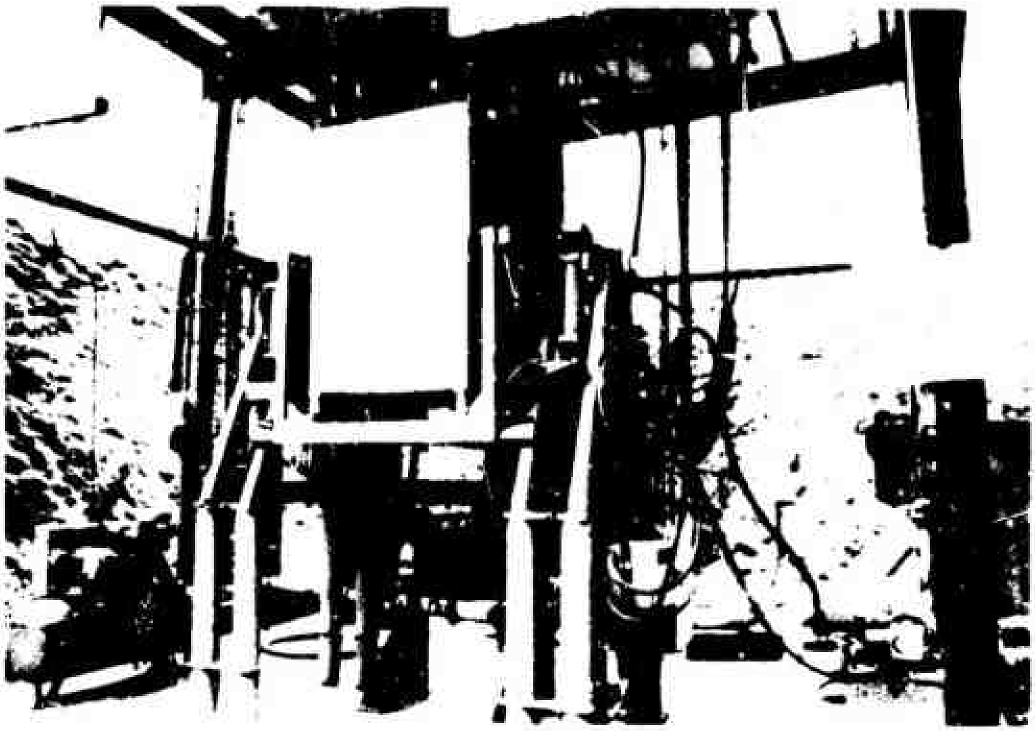


Figure 32

PRIMARY ADVANTAGES
OF
NEW TNT FACILITIES

47% REDUCTION IN PERSONNEL

REMOTE CONTROL

COMPUTER OPERATIONS

75% REDUCTION OF EXPLOSIVES IN PROCESS

42% REDUCTION IN OPERATING COSTS

99% REDUCTION IN POLLUTION EMISSIONS

Figure 33

ECONOMIC ANALYSIS

FACILITY	OLD	NEW	COST REDUC
60% NITRIC	$ 24 TON	$ 12 TON	50%
98% NITRIC	$ 57 TON	$ 30 TON	48%
OLEUM	$ 17 TON	$ 6 TON	65%
TNT	$272 TON	$160 TON	42%

Figure 34

SUMMARY

CILITY	COST REDUCTION	POLLUTION REDUCTION	PERSONNE REDUCTIO
AOP	50%	96%	60%
DSN	48%	90%	25%
SAR	65%	97%	40%
TNT	42%	95%	43%

Figure 35

CASE STUDY OF PLANT MODERNIZATION AT LAKE CITY ARMY AMMUNITION PLANT

CPT D. E. O'Brien, USA, Executive Officer
Lake City Army Ammunition Plant, Independence, Mo.

INTRODUCTION

I am Captain O' Brien, Executive Officer, Lake City Army Ammunition Plant. My case study on modernization will cover the status of the Lake City Modernization Program.

CHART I - PLANT PICTURE

Lake City is a modern GOCO small arms ammunition facility located 17 miles east of Kansas City. The plant is operated by Remington Arms Company, Inc., under a cost-plus-incentive-fee contract.

CHART 2 - ITEMS OF PRODUCTION

This chart illustrates the items that LCAAP is capable of producing. The underlined items are currently not in production.

CHART 2a - BALL BULLET PRODUCTION LAYOUT

CHART 3 - SCAMP COVER

The Modernization Program for Lake City is referred to as SCAMP which is the Small Caliber Ammunition Modernization Program. Frankford Arsenal located at Philadelphia, Penn., is responsible for the over-all management of the total SCAMP Program. I will today only discuss the Lake City portion of the program.

CHART 4 - SCAMP OBJECTIVES

The initial search for modern technology for small caliber ammunition production was initiated at Frankford Arsenal in mid-1968. Thirty to fifty year old facilities built from technology of the 1920's comprise the current small caliber ammunition production base. Over the years these production lines have been significantly improved, but their production rate potential has been reached because of limitations imposed by the human element. Recent usage rates have so nearly approached maximum production rates that we now have very little emergency production capacity. Further, this well worn equipment creates pollution and less than ideal working conditions in contravention of Executive Order No. 11507, and the Occupational Safety & Health Act of 1970. Clearly replacement of the current production equipment is the only logical means of overcoming these problems, and it is urgent. In order to establish a means of evaluating concepts and improvement, a series of objectives to be achieved and benefits to be derived have been established. They are:

1. To achieve a substantial reduction in inventory on hand and requirements for storage space through decreased production lead time and increased production rates.

2. To reduce cost of manufacturing by reducing manhours required. Reducing maintenance cost, improving tool life and increasing machine efficiency.

3. To improve quality of product and reduce scrap through better controls, better processes and continuous inspection.

4. To reduce firing test costs, time, quantities fired and inventory held pending completion of tests by use of automated on-line testing and improved quality of product.

5. To improve ability to meet changing mobilization and peacetime requirements through versatility and flexibility, i.e., of metals; conversion within defined limits to manufacturing of new generation cartridges; and most important of all, replacement of an obsolete base.

6. To improve environmental conditions at the work site and in the community through better pollution control, application of human engineering, and reduction in working hazards.

CHART 5 - OPERATIONAL CRITERIA

This viewgraph illustrates the operational criteria developed as the standards for SCAMP. Each aspect of the criteria was developed for a specific operational purpose. The safety criterion was applied throughout the development of the operational criteria on the SCAMP concept as well as in the initial design.

CHART 6 - SCAMP PRODUCTION COMPARISON

I would like to show you a typical comparison of the new SCAMP

equipment as opposed to current production equipment. The graphs show that the current production facility needs over 550, 000 square feet of space while the new modern facility needs only 120,000 square feet. Personnel would be reduced approximately 87% and the 775 machines necessary would be reduced to 120. As can be seen from these figures manhour exposure to safety hazards would be greatly reduced. As I address each of the separate submodules later in the briefing I will discuss each of the four areas of safety improvement. As I stated earlier, SCAMP has greatly reduced the number of personnel and the amount of machinery hence lowering the exposure to hazards. In many areas operational personnel have been completely removed from hazardous areas due to remote control operation and shielding. SCAMP has been designed from the start with safety procedures and pollution control as part of the basic design. This and operational criteria have been formulated to comply with the Occupational Safety & Health Act and the total program has been and will be human engineered throughout its life.

CHART 7 - SCAMP MODULAR LAYOUT

We see here the layout of typical small arms ammunition machinery. As I mentioned earlier, all the components in small arms ammunition production are contained within the module, such as the bullet, etc.

8 - FILM

I would now like to show you a short film comparing the current process for fabricating the cartridge case with that being developed for SCAMP. We see here a typical 5.56mm cartridge case operation. It is a batch process with a large number of machines performing single operations at rates of approximately 100 parts per minute. A typical line producing 130 million cases per month requires approximately 380 machines. This equipment and its support requires approximately 100,000 square feet of floor space and 500 direct operating personnel.

Now we see the automated cartridge case machinery being developed by Gulf & Western Industries to replace older equipment. This new system utilizes a series of rotary turret presses to perform the various metal working operations.

The over-all system is controlled by the master control console shown here. Parts are carried between the presses in captive oriented position by a series of transfer chains. Operations are inspected as they are performed and defective parts are rejected prior to entering the next operation.

Initial forming operations for the cartridge case are performod in these presses. Each press contains 24 tool stations with individual

tools operated by a fixed cam as the turret rotates around it. Tools and other parts subject to wear are modular and can be replaced in 10 minutes or less. The tool module being removed from this press is the heaviest of all the tool modules and weighs approximately 40 pounds.

CHART 9 - CURRENT PRIMER INSERT

This is our current primer insert operation for inserting primers in finished cartridge cases. This operation consists of 44 personnel and 48 pieces of machinery. As you can see this is a batch operation with a great deal of equipment on line.

CHART 10 - SCAMP PRIMER INSERT

The SCAMP machinery for primer insertion retains the rotary turret concept as developed for the case. This is one of the four most explosive hazardous areas in small arms ammunition production. This new machinery clearly reduces the number of personnel and potential hazard. This reduction in personnel coupled with the inherent safety design of the machinery greatly increases primer insert operational safety.

CHART 11 - CURRENT BULLET JACKET DRAW

The bullet operation consists of a bullet jacket draw, the trim,

and assembly. This chart shows the bullet jacket draw process.

CHART 12 - CURRENT BULLET JACKET TRIM

This chart shows the bullet trim operation. Again I call your attention to the large amount of machinery and personnel necessary for operation.

CHART 13 - CURRENT BULLET ASSEMBLY

This last chart shows final bullet assembly as it is currently done. In this operation the lead slug is placed in the bullet and the bullet jacket is formed.

CHART 14 - SCAMP BULLET SUBMODULE

The SCAMP bullet submodule combines the three operations. This submodule produces the same number of bullets as three draw presses, 10 trim machines, and 9 assembly machines under our current process. The new machines clearly increase product control which is critical in the bullet forming operation due to the need to hold ballistic flight characteristics constant.

One additional operation I wish to discuss is the loading of tracer mix into the bullet. This also is an extremely hazardous operation. Under SCAMP, this operation is totally remote controlled as it is encased in a separate barricaded area with no personnel present.

CHART 15 - CURRENT LOAD AND ASSEMBLY

This chart shows the current load and assembly operation. In this operation ball powder is poured into the case and the cases and the bullets are placed in trays and crimped together. As you can see this operation requires a great deal of machinery and direct personnel contact with potential explosive hazards.

CHART 16 - SCAMP LOAD AND ASSEMBLY

This chart illustrates the SCAMP load and assembly machinery which is remote controlled and greatly reduces the number of people directly exposed to explosive hazard.

CHART 17 - CURRENT PRIMER RUBBING

This photograph shows the current primer rubbing operation. As you can see this man is directly exposed to the hazard of primer explosive, as he hand rubs wet primer mix over the primer cups.

CHART 18 - CURRENT PRIMER MANUFACTURE

This shows the number of people working in conjunction with the rubbing man and in primer manufacturing. Approximately 13 people are required to produce the equivalent of the SCAMP machinery.

CHART 19 - SCAMP BENDIX PRIMER MANUFACTURING

This chart shows one of the two methods being pursued for automation

of primer manufacturing. This automatic operation is totally remote controlled from behind a steel barricade with an automatic water deluge operation. Automatic primer manufacture will reduce almost all of the current personnel potential hazards in primer manufacturing.

CHART 20 - CURRENT PACKAGING LINE

This slide illustrates the current packing operation. This operation requires the largest number of direct personnel in small arms assembly. SCAMP will allow a substantial reduction in these personnel.

CHART 21 - SCAMP CLIPPING OPERATION

This chart shows the automatic clipping operation as part of SCAMP. After clipping the ammunition is fed down to the packing area and then to crating and banding.

CHART 22 - SCAMP PALLETIZING AND BANDING LINE

Palletizing and banding shown on this chart is totally automated. Crating and banding is an area in the current operation in which we have many minor injuries, such as fingers being pinched or cut. The automatic packaging machinery will totally eliminate this hazard.

CHART 23 - CURRENT BALLISTICS OPERATION

This chart illustrates the current ballistic test operation highlighting the large number of bays and personnel necessary for function and casuality testing of finished ammunition.

CHART 24 - SCAMP BALLISTICS OPERATION

This schematic highlights the new procedure for ballistic testing for both function and casualty and accuracy. This will greatly reduce the number of personnel actually firing weapons and allow instantaneous recording of pass or fail data.

CHART 25 - PQCS QUALITY CONTROL MACHINERY

This chart shows the basic layout of the computerized quality control operation which allows for rapid dissemination of quality fault data. This system clearly reduces the number of direct personnel involved in inspection. Many of the PQCS (Process Quality Control System) features will be highlighted in the film I will show shortly.

CHART 26 - SCAMP SAFETY

The SCAMP office has carried out a comprehensive life cycle safety program in accordance with MIL-STD 882, Requirements for System Safety Program for Systems and Equipment. In the current hardware contracts for the primer insert, tracer charging and load and assembly

equipment, failure mode and hazardous effects analyses are being carried out utilizing inputs from the previous preliminary hazard analyses to correct potential hazard areas. This systematic approach has been broadened by the SCAMP office to include operational and maintenance functions; thus, safety has been made an important factor in planning as opposed to a requirement to be met after the equipment is designed.

In all hardware contracts the SCAMP office has required conformance to applicable industry standards, such as the Underwriters Standards and the National Electrical Code; Army Materiel Command Regulations, such as AMCR 385-100, Safety Manual; and AR 385-30, Safety Code; and the Safety and Health Standards of the Federal Register which contains the requirements of the Occupational Safety & Health Act of 1970.

Finally, the SCAMP office has supervised the development of new concept operational shielding for primer trays which virtually eliminates the hazards of explosion in bulk primer transport. This concept, which may also be beneficial to present operations, represents a truly significant advance in safety to the small caliber ammunition manufacturing field.

Human Factors Engineering - In every hardware development project the SCAMP office has required competent human factors engineering programs in accordance with MIL-STD-1472, Human Factors Engineering Design Criteria. These programs are monitored by both SCAMP/LCAAP and the Frankford Arsenal Human Factors Branch. In addition, special studies in the areas of personnel hazards are being carried out. The basis for these studies are the OSHA Standards and include the following:

1. Acoustic Analysis of SCAMP Equipment and proposed installations.

2. Noise Abatement in SCAMP Equipment--Goal is 85db"A: Maximum (about the noise of an indoor kindergarten play period).

3. Vibration and impact noise analysis and control.

4. Lighting for operation and maintenance.

Pollution Control - These efforts for the SCAMP Program concentrate on the high emission area, namely, the case and bullet submodules allow the use of heat, acids, and other chemicals to achieve required hardness and metallurgical properties as necessary. Planned work consists of developing means for recovery and reuse of valuable draw lubricants and pickling solutions.

Since the effluents involved with SCAMP machinery are similar to those now encountered, the new methods of treatment and/or recovery should be applicable to present systems also.

CHART 27 - FINAL FILM

In summing up this case study I would like to show you a short film. The film illustrates the ways we are moving in quality control and the methodology and computerization being used throughout the total program. The film was prepared by Batelle Industries.

CONCLUSION

This film and discussion illustrates the type of work being done for and at LCAAP in SCAMP. In conclusion the best way to describe the safety aspects of the program is to say that the total program was designed from the start with safety a paramount consideration in modernization. This total design has caused a significant reduction in personnel exposure to hazards. The operational design itself has even reduced the hazards to a greater degree. The operational design requiring automated remote control, easy modular tool removal and less machinery greatly contributes to this reduction of the safety hazard. It is the over-all safety criteria on the SCAMP machinery, coupled with the operational criteria, that has made the SCAMP

concept a tremendous improvement over our current batch line operation.

CHARTS

LAKE CITY

ARMY AMMUNITION PLANT

REMINGTON ARMS CO. INC. OPERATING CONTR.

COVER CHART

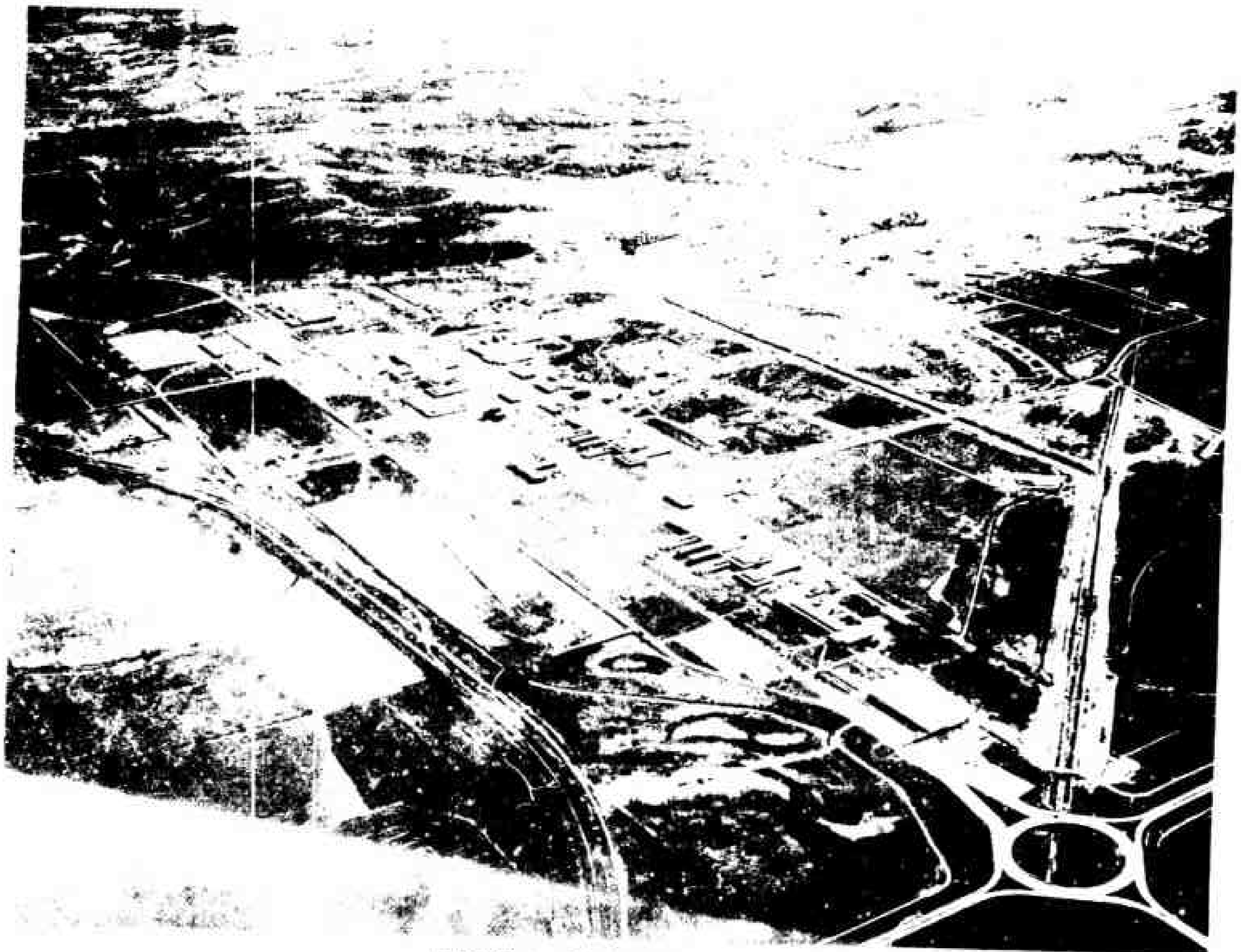


CHART 1 - PLANT PICTURE

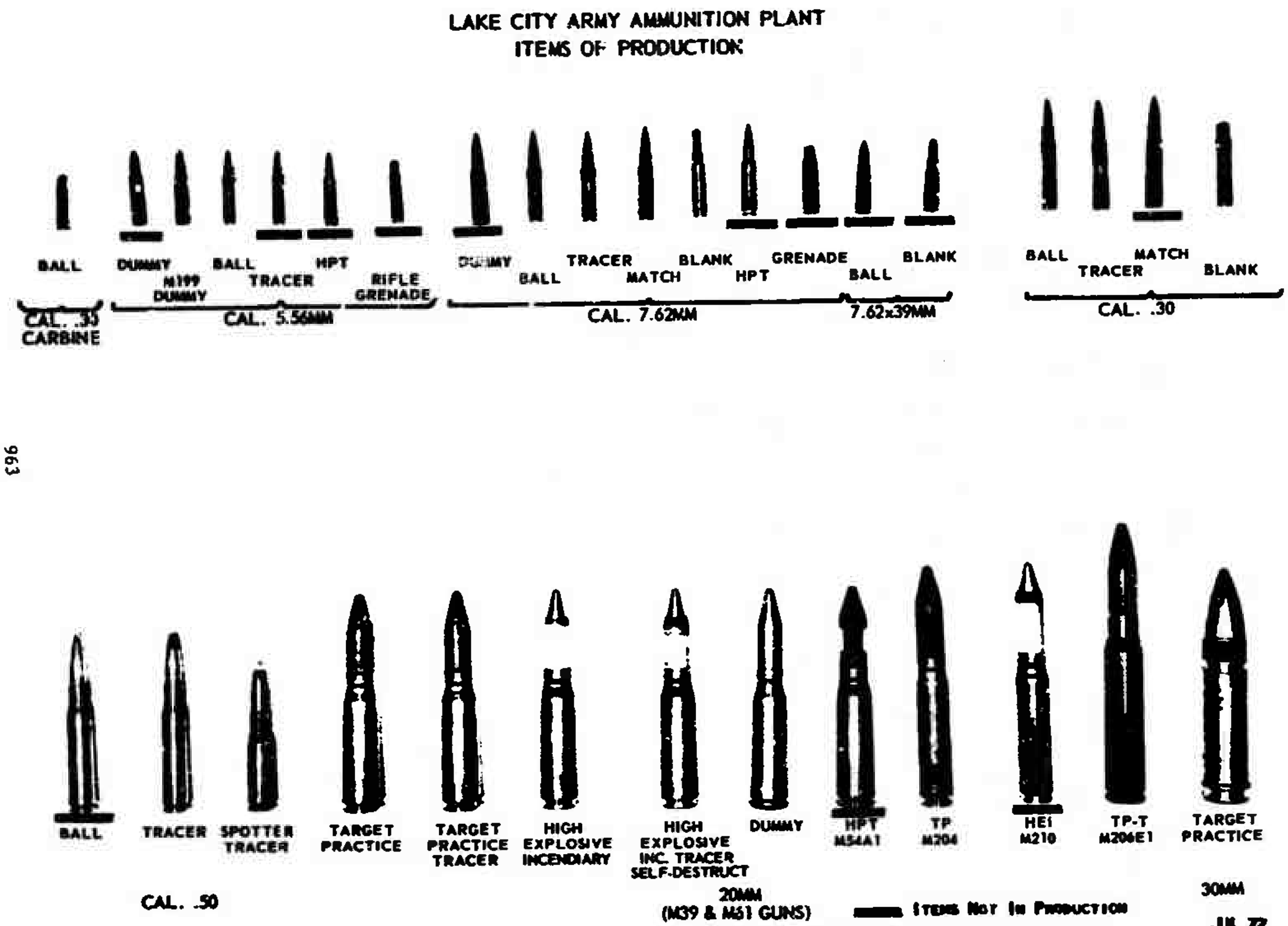


CHART 2 - ITEMS OF PRODUCTION

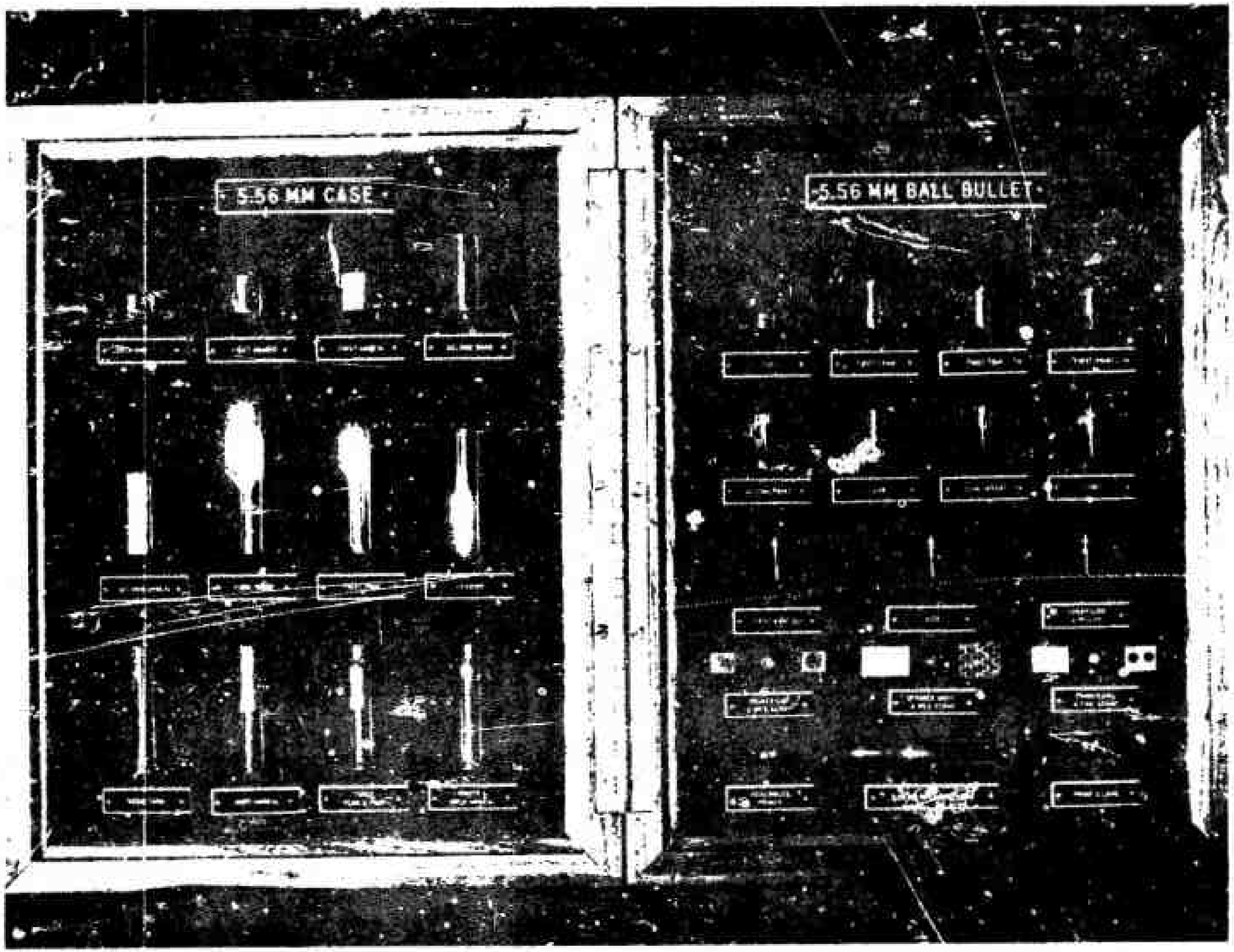


CHART 2a - BALL BULLET PRODUCTION LAYOUT

CHART 3 - SCAMP COVER

OBJECTIVES OF MODERNIZATION

OBJECTIVE		BENEFITS
DECREASE LEAD TIME INCREASE PRODUCTION RATE	=	REDUCED INVENTORIES ON HAND AND STORAGE SPACE REQUIRED
DECREASE MAINTENANCE COSTS REDUCE LABOR IMPROVE TOOL LIFE INCREASE MACHINE EFFICIENCY	=	REDUCED COSTS OF MANUFACTURE
BETTER CONTROLS BETTER PROCESSES CONTINUOUS INSPECTION	=	IMPROVED QUALITY OF PRODUCT AND REDUCE SCRAP
AUTOMATE FIRING TESTS IMPROVE QUALITY	=	REDUCTION IN TIME AND COST OF TESTING, QUANTITY FIRED, AND INVENTORY HELD PENDING COMPLETION
REPLACE OBSOLETE BASE CONVERSION OF CALIBERS CONVERSION TO OTHER METALS CONVERSION TO FUTURE ROUNDS	=	IMPROVED MOBILIZATION AND PEACE-TIME RESPONSE
POLLUTION CONTROL HUMAN ENGINEERING HAZARD REDUCTION	=	IMPROVE ENVIRONMENTAL CONDITIONS

FRANKFORD ARSENAL ● PHILADELPHIA, PA.

CHART 4 - SCAMP OBJECTIVES

OPERATIONAL CRITERIA

- OPERATING SPEED OF 1200 ROUNDS PER MINUTE
- TRANSFER COMPONENTS IN A CAPTIVE WORK ORIENTED POSITION
- IN-PROCESS AUTOMATED INSPECTION
- DESIGN FOR PREVENTIVE MAINTENANCE
- ECONOMICAL OPERATION AT LESS THAN DESIGN SPEED
- COMPUTERIZED QUALITY CONTROL AND PRODUCTION MANAGEMENT DATA
- MODULAR CONCEPT FOR TOOLING

CHART 5 - OPERATIONAL CRITERIA

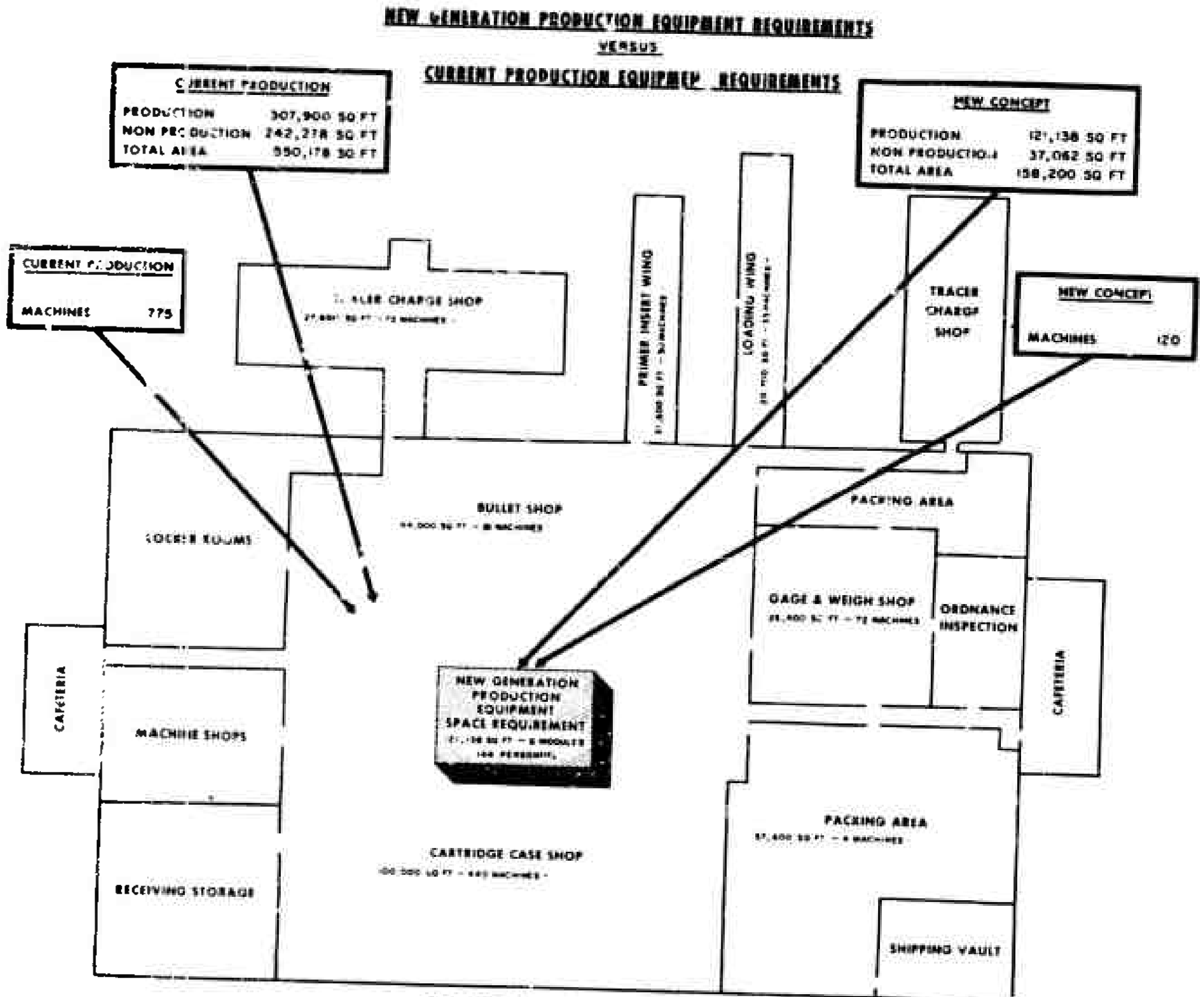


CHART 6 - SCAMP PRODUCTION COMPARISON

SMALL CALIBER AMMUNITION PRODUCTION MODULE

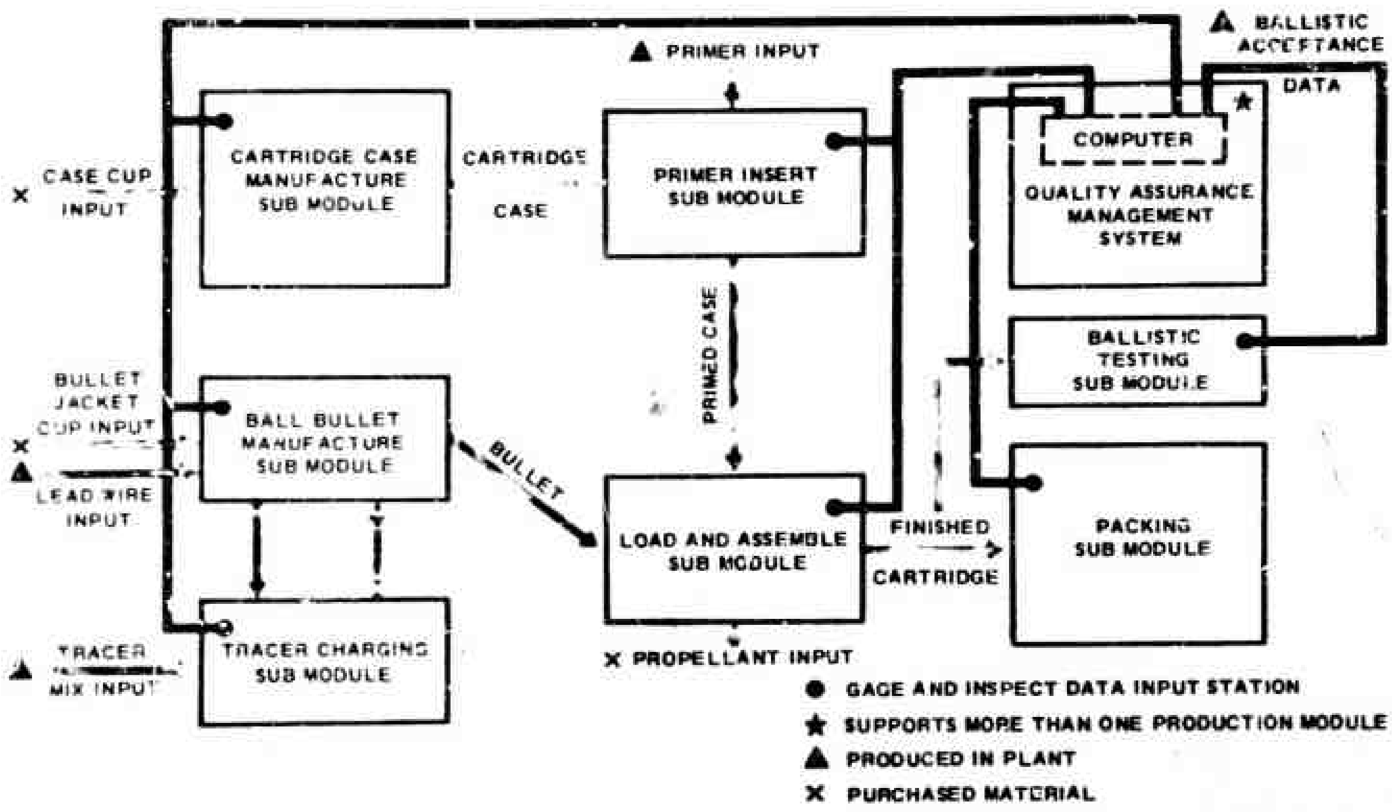


CHART 7 - SCAMP MODULAR LAYOUT

Bldg. 4 CALIBER 30 CARBINE AND 5.56MM.
CASE PRIMING AREA

CHART 9 - CURRENT PRIMER INSERT

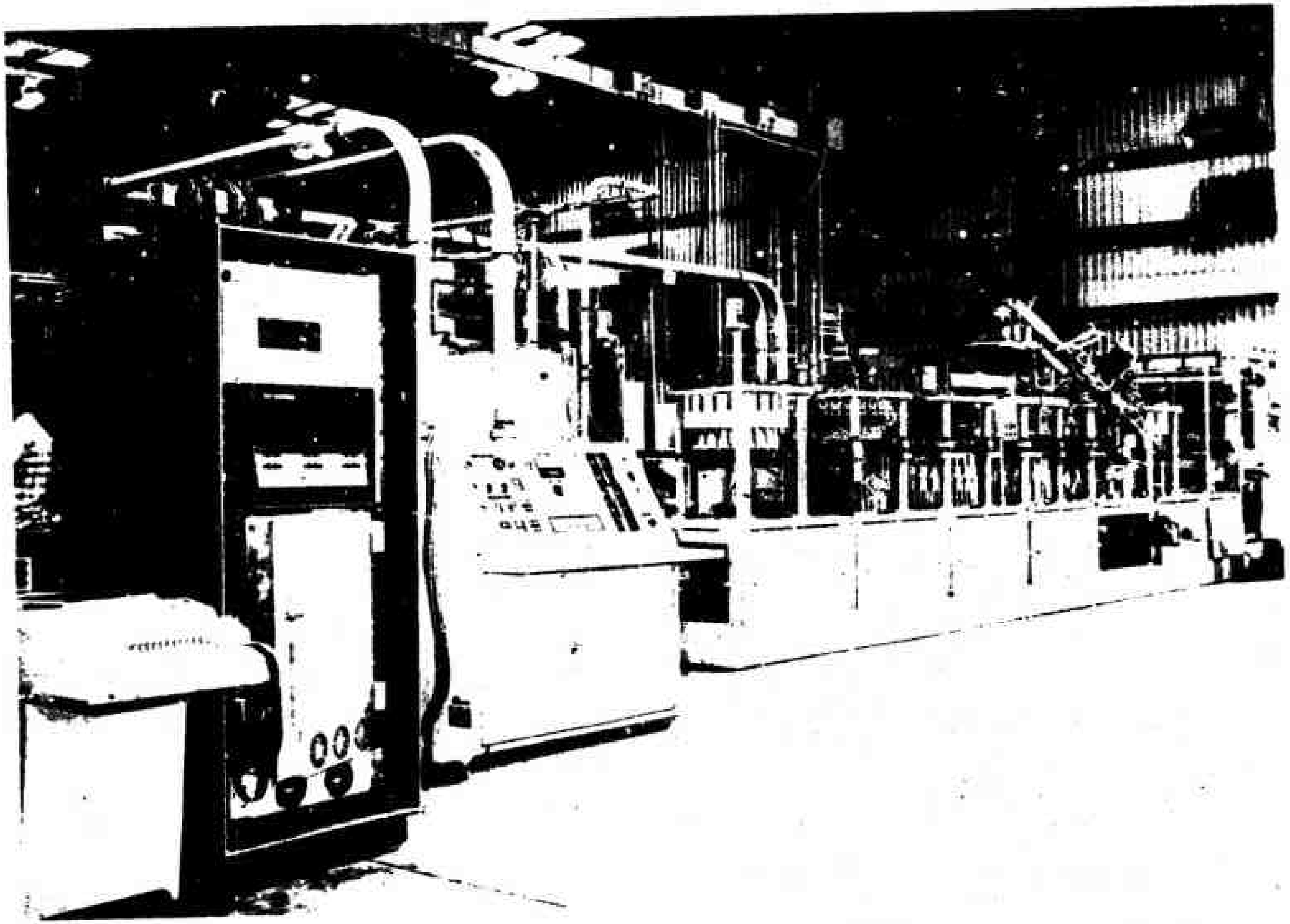
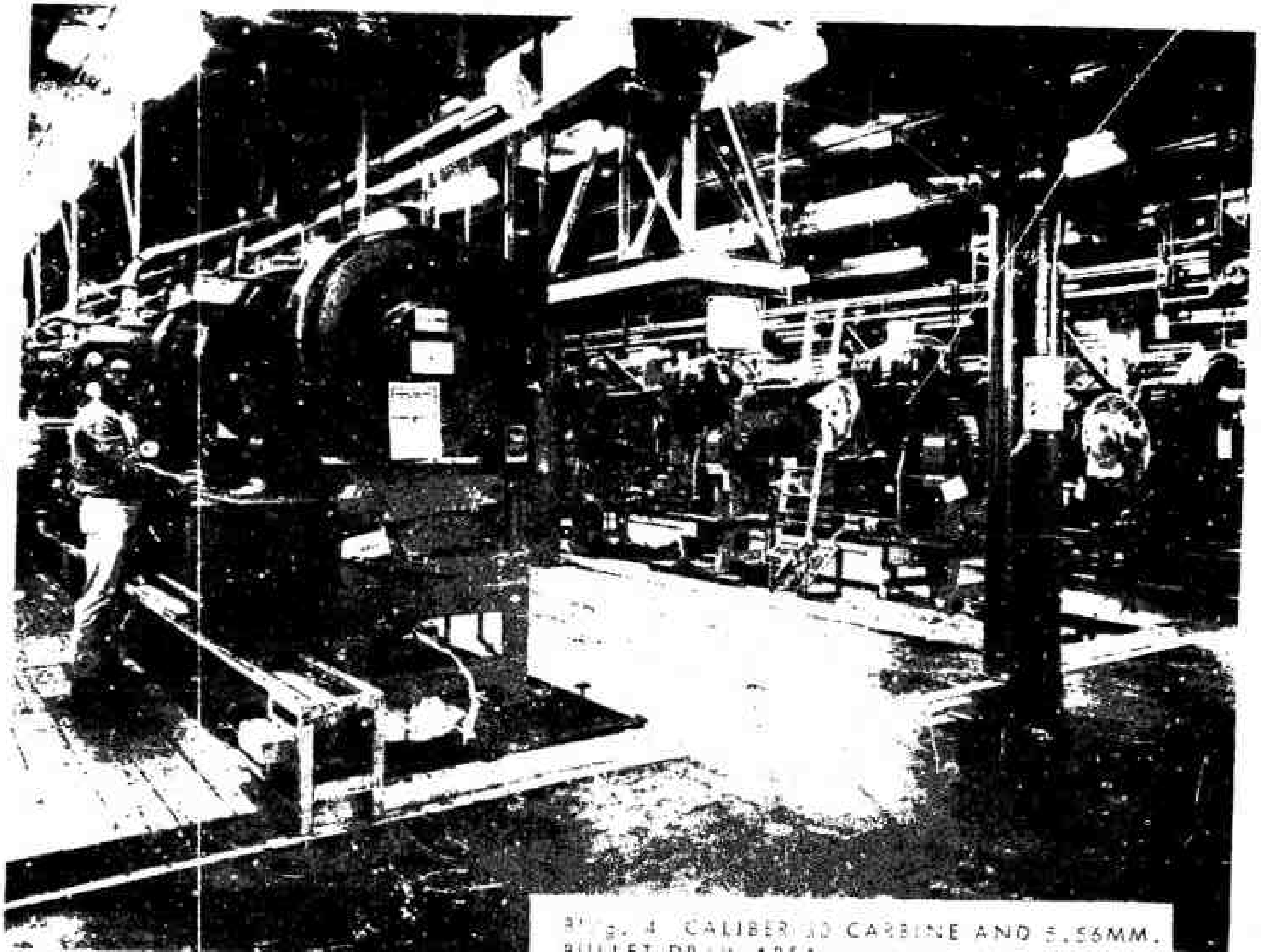


CHART 10 - SCAMP PRIMER INSERT



Bldg. 4 CALIBER .30 CARBINE AND 5.56MM.
BULLET DRAW AREA

CHART II - CURRENT BULLET JACKET DRAW

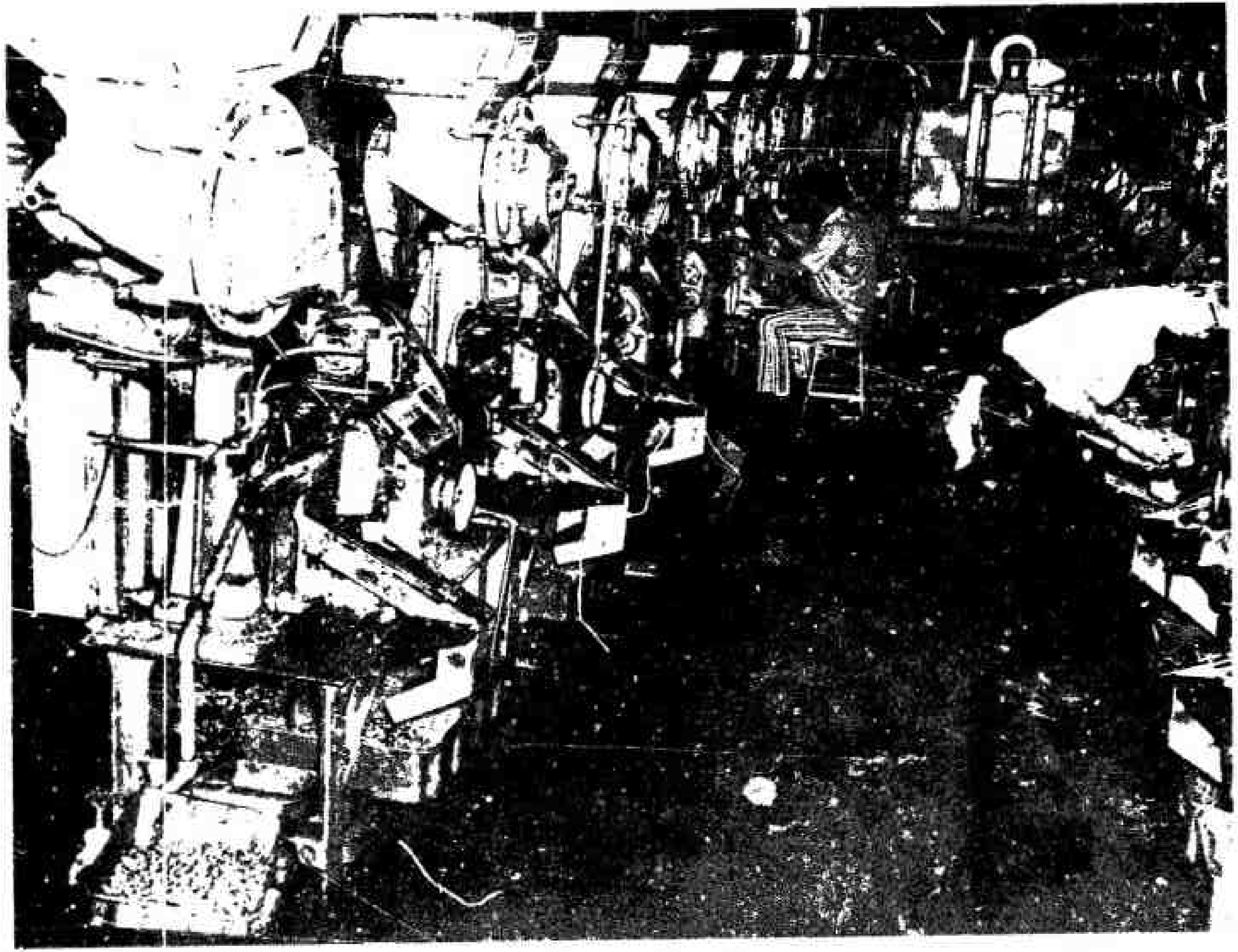


CHART 12 - CURRENT BULLET JACKET TRIM

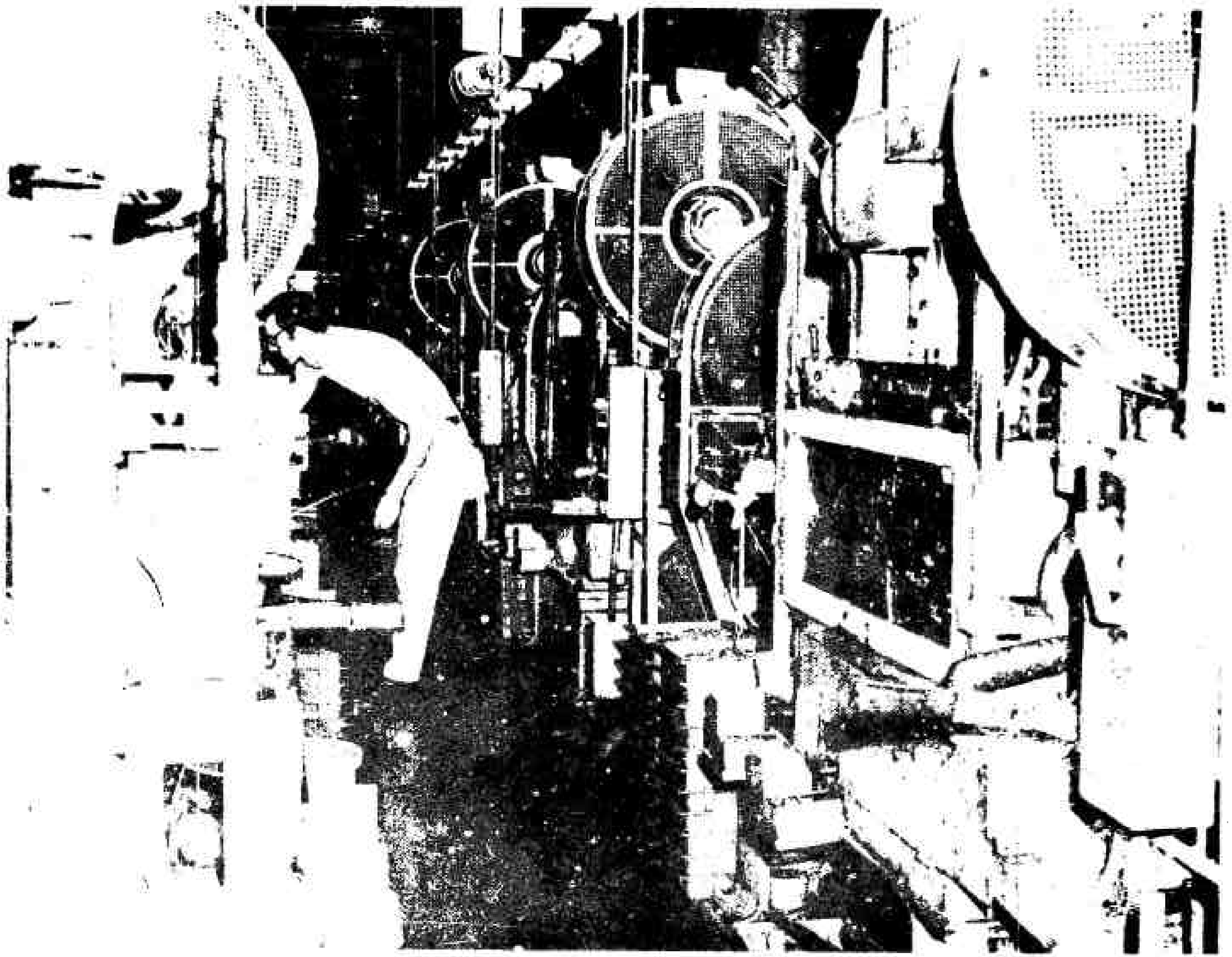


CHART 13 - CURRENT BULLET ASSEMBLY

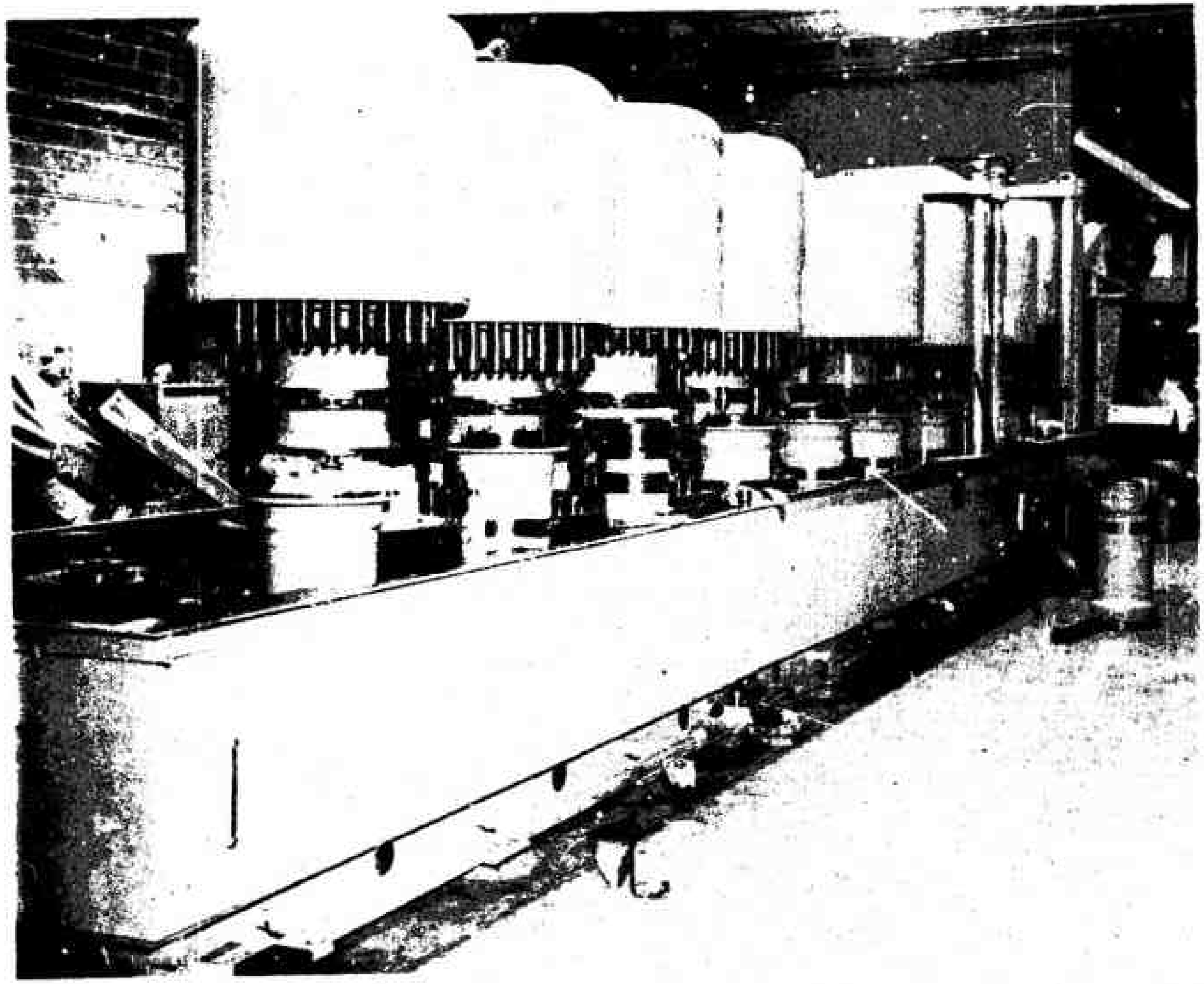
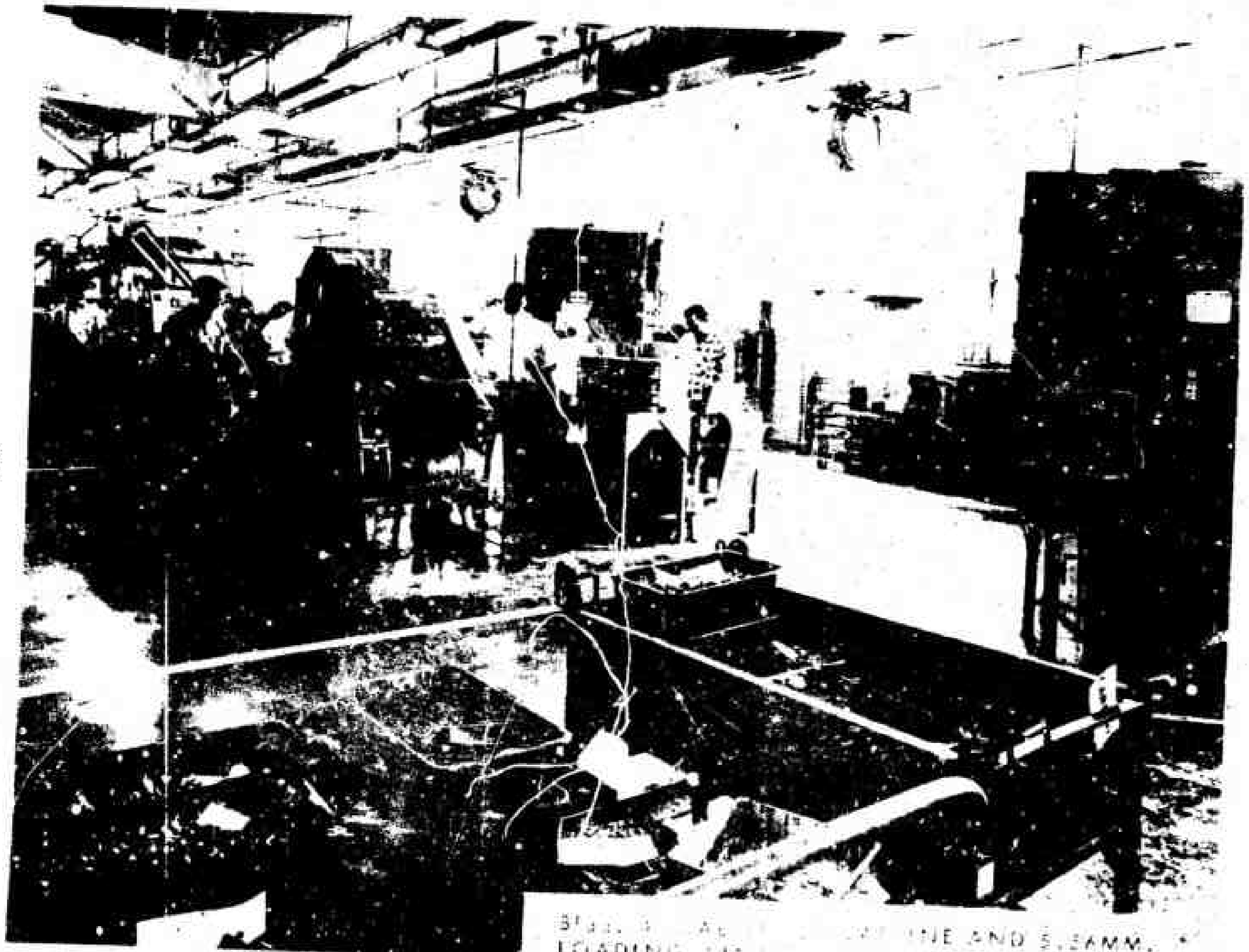


CHART 14 - SCAMP BULLET SUBMODULE



... LOADING ... LINE AND 5.56MM ...
CHART 15 - CURRENT LOAD & ASSEMBLY

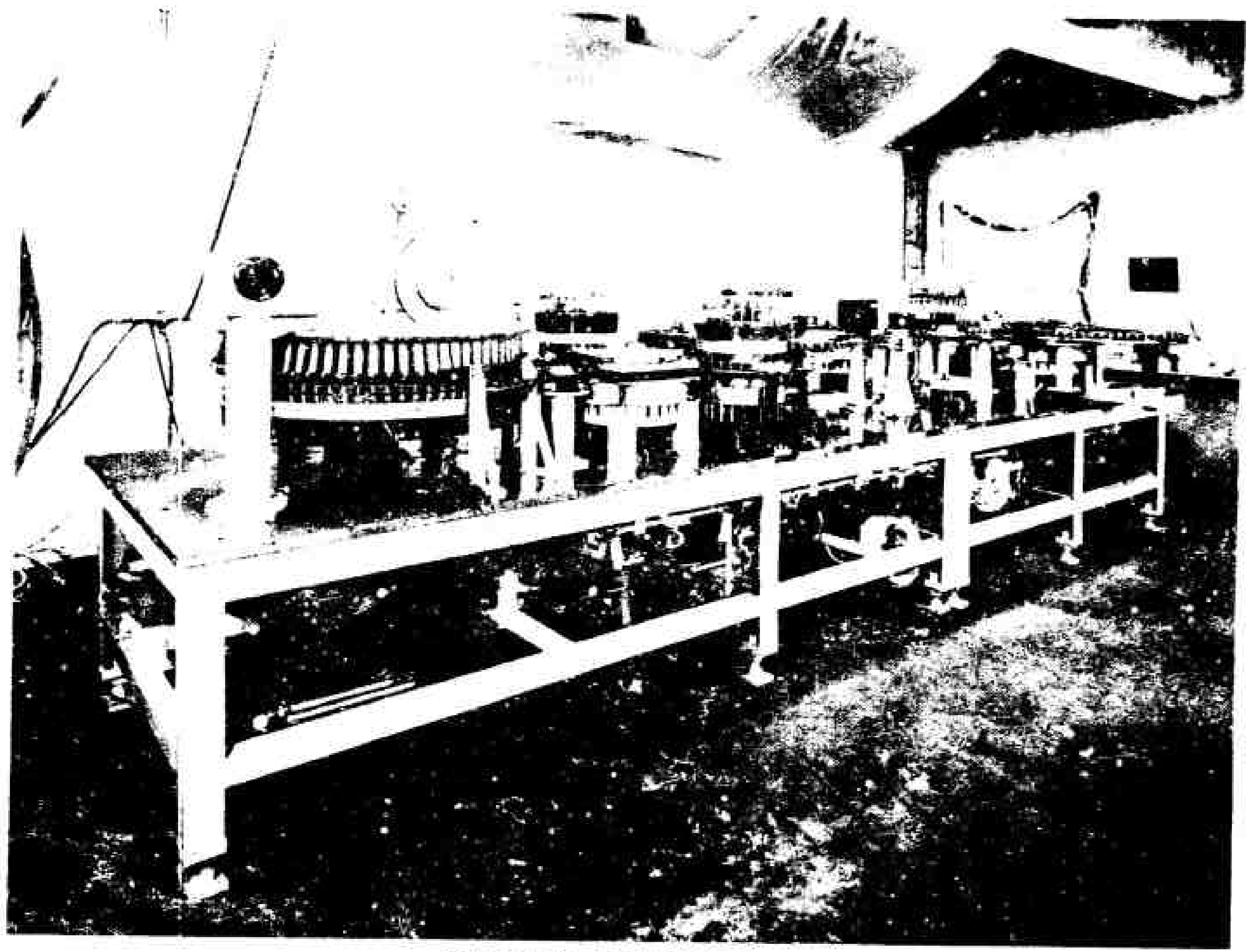


CHART 16 - SCAMP LOAD & ASSEMBLY

CHARGING WING.

CHART 17 - CURRENT PRIMER RUBBING

CHART 18 - CURRENT PRIMER MANUFACTURING

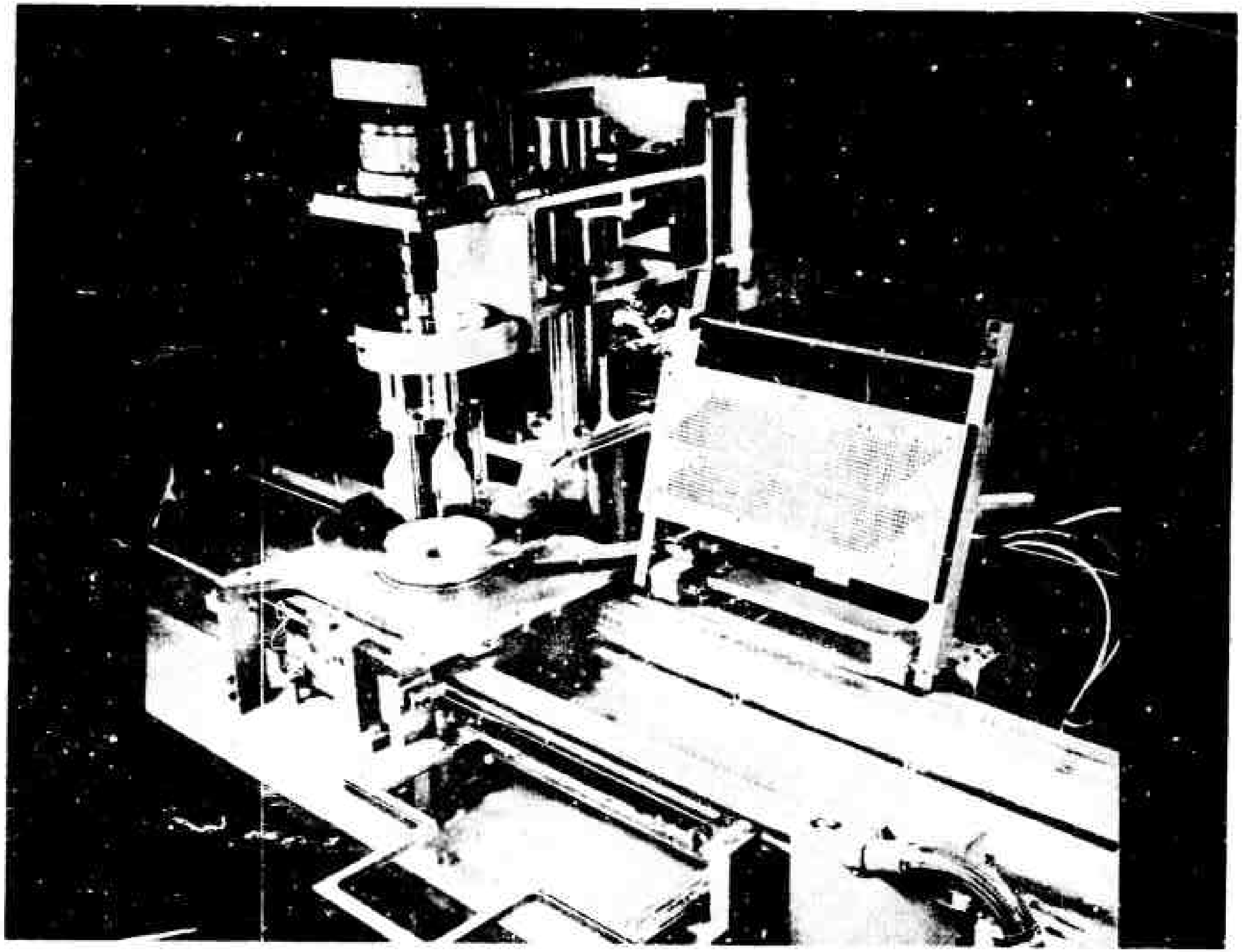


CHART 19 - SCAMP BENDIX PRIMER MANUFACTURE

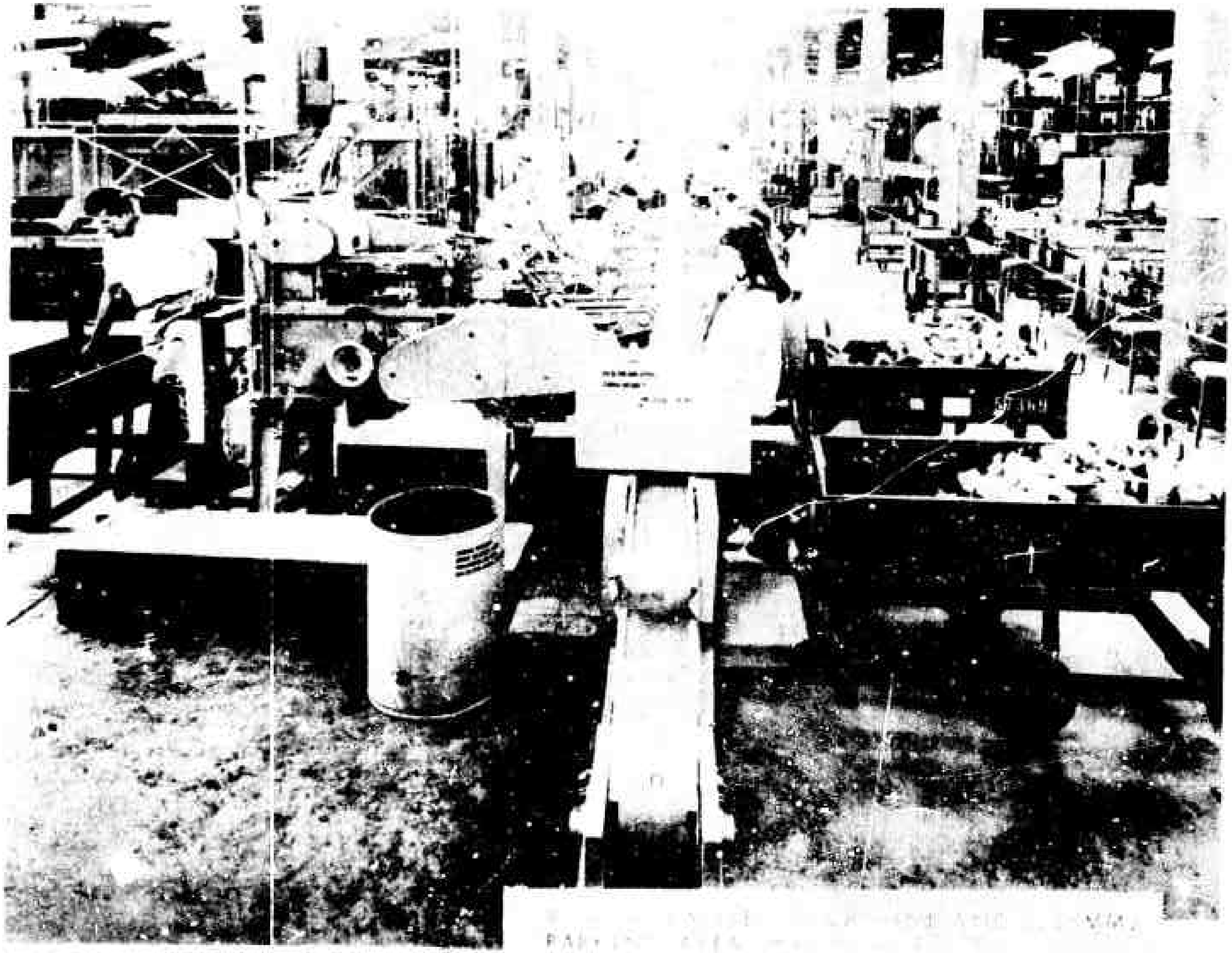


CHART 20 - CURRENT PACKAGING LINE

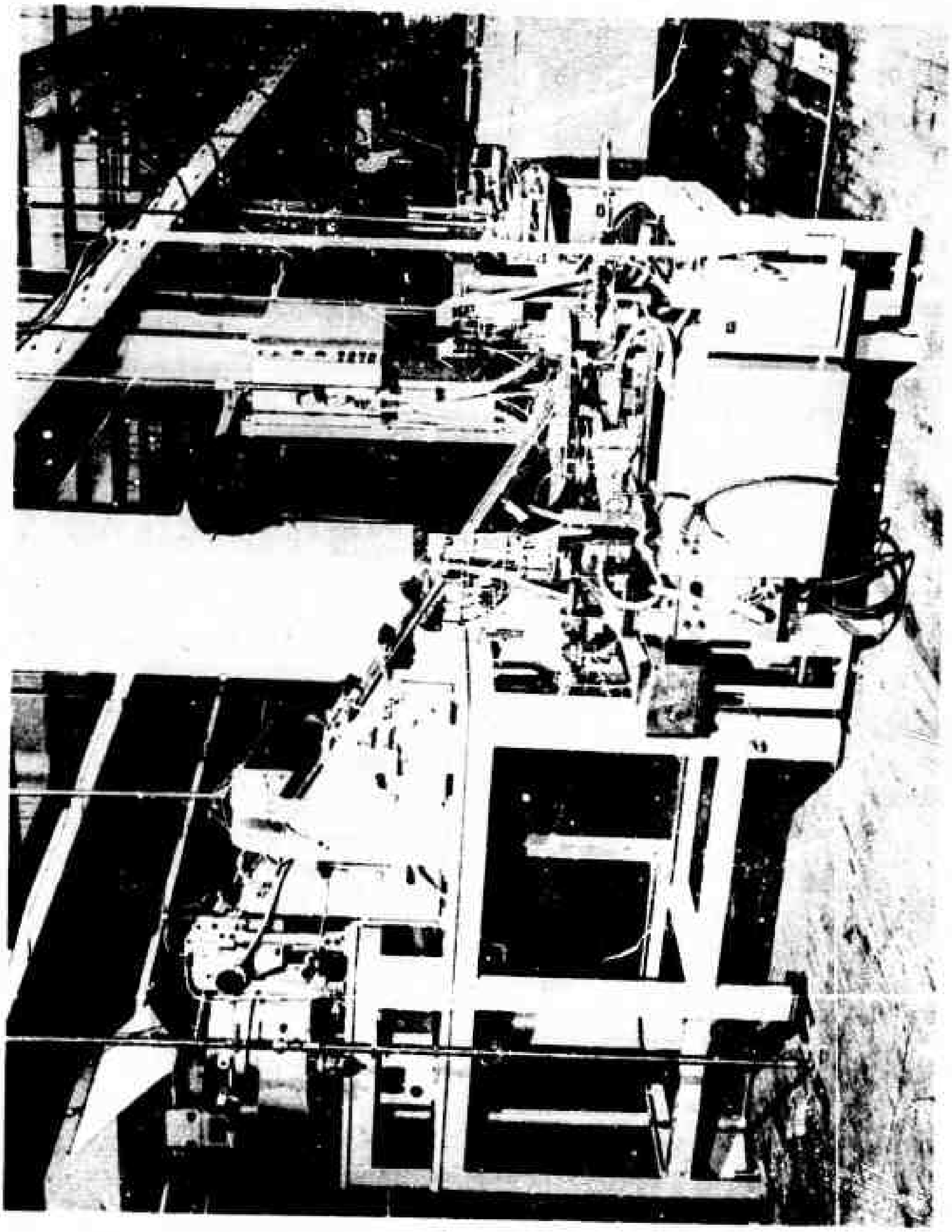


CHART 21 - SCAMP CLIPPING OPERATION

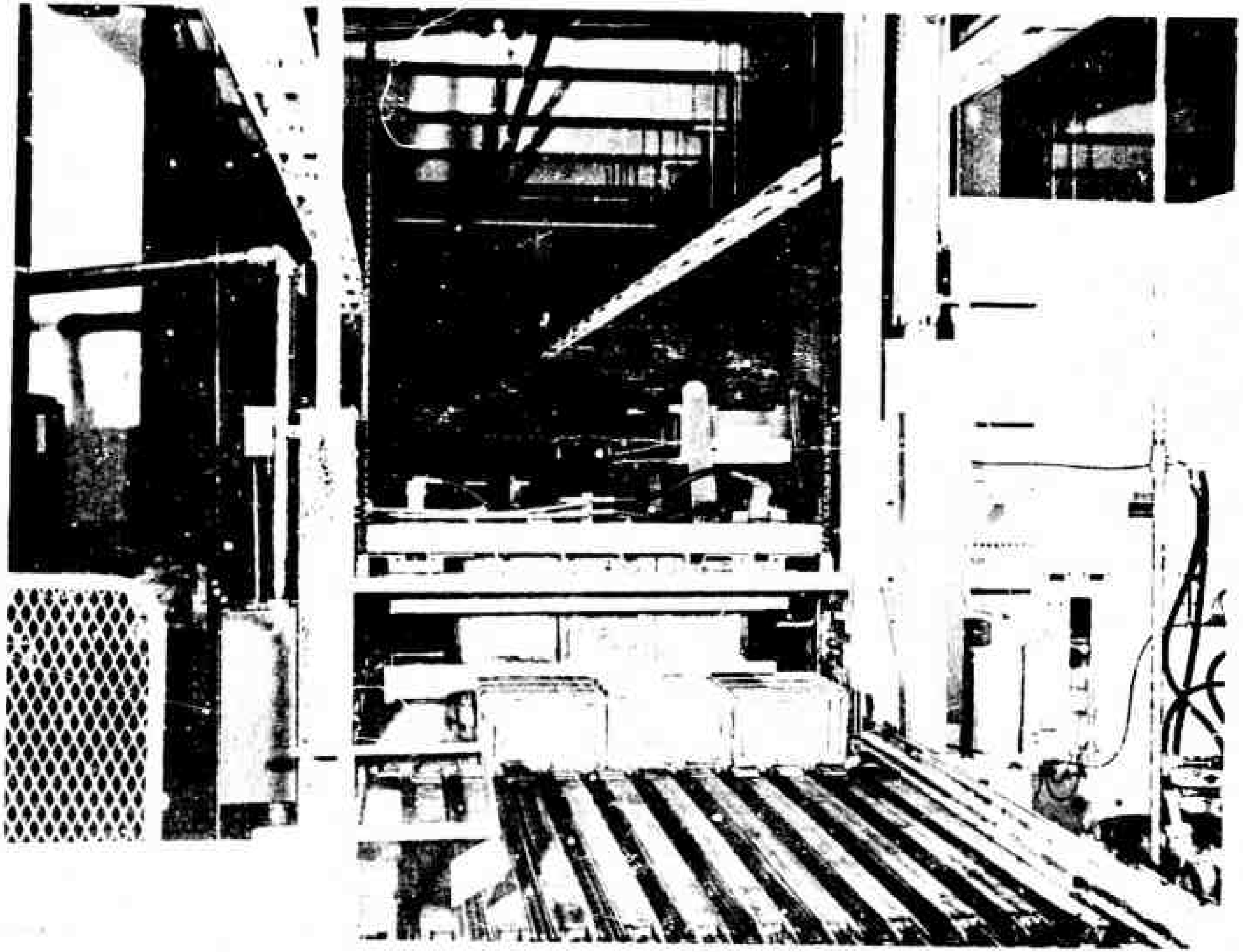
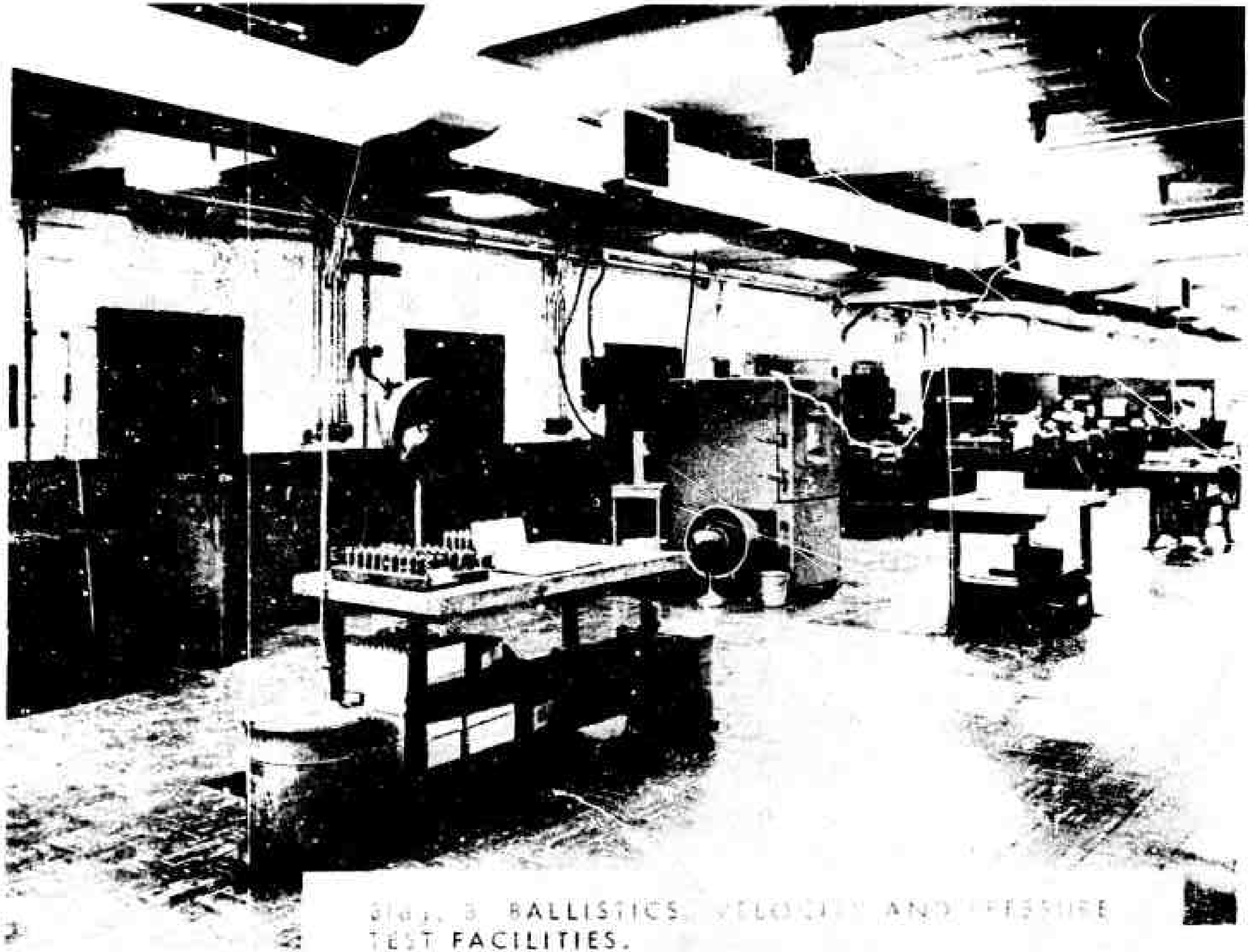


CHART 22 - SCAMP CRATE & BANDING LINE



Bldg. 5 BALLISTICS, VELOCITY AND PRESSURE
TEST FACILITIES.
CHART 23 - CURRENT BALLISTICS OPERATION

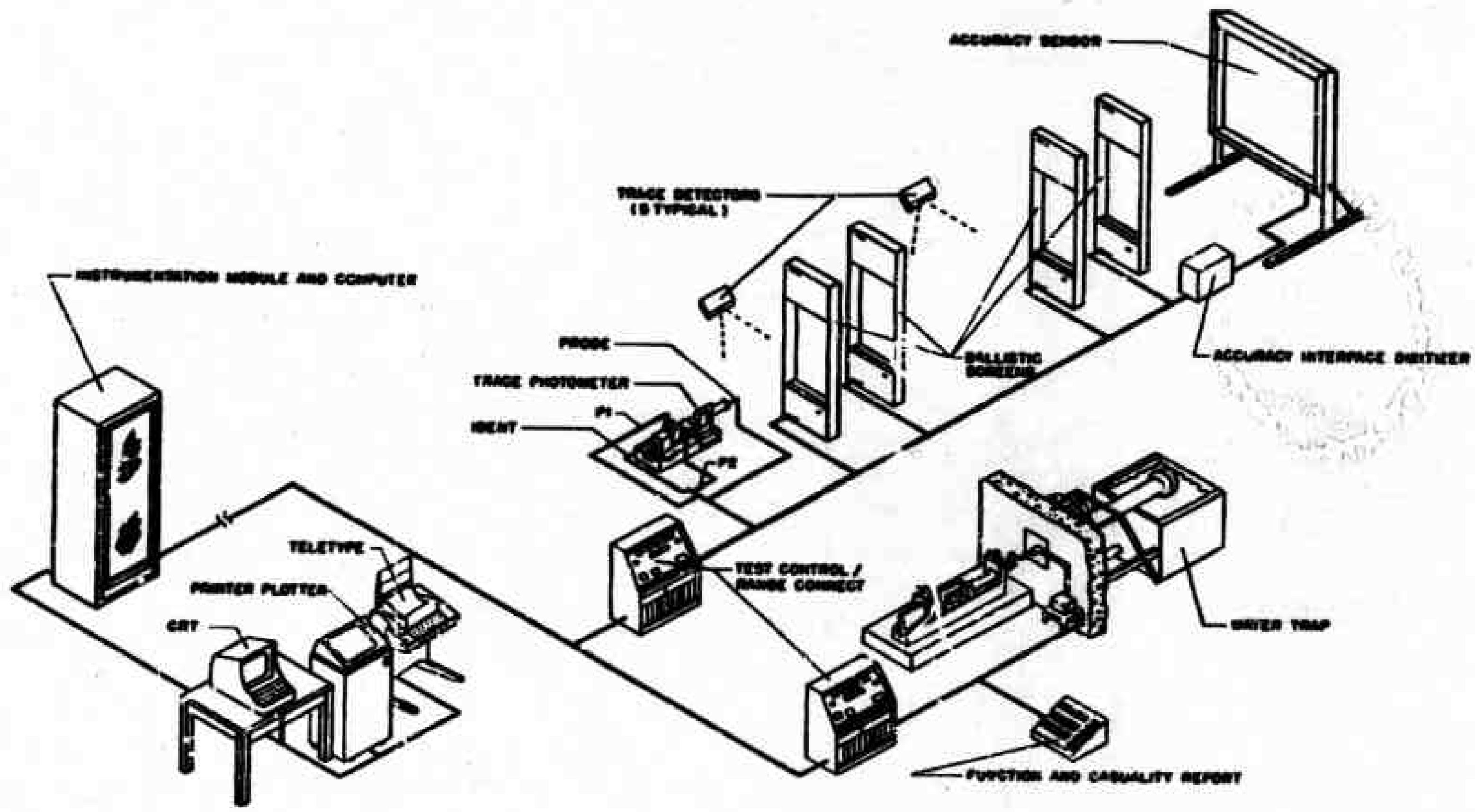


CHART 24 - SCAMP BALLISTICS

PQCS CONTROL ROOM

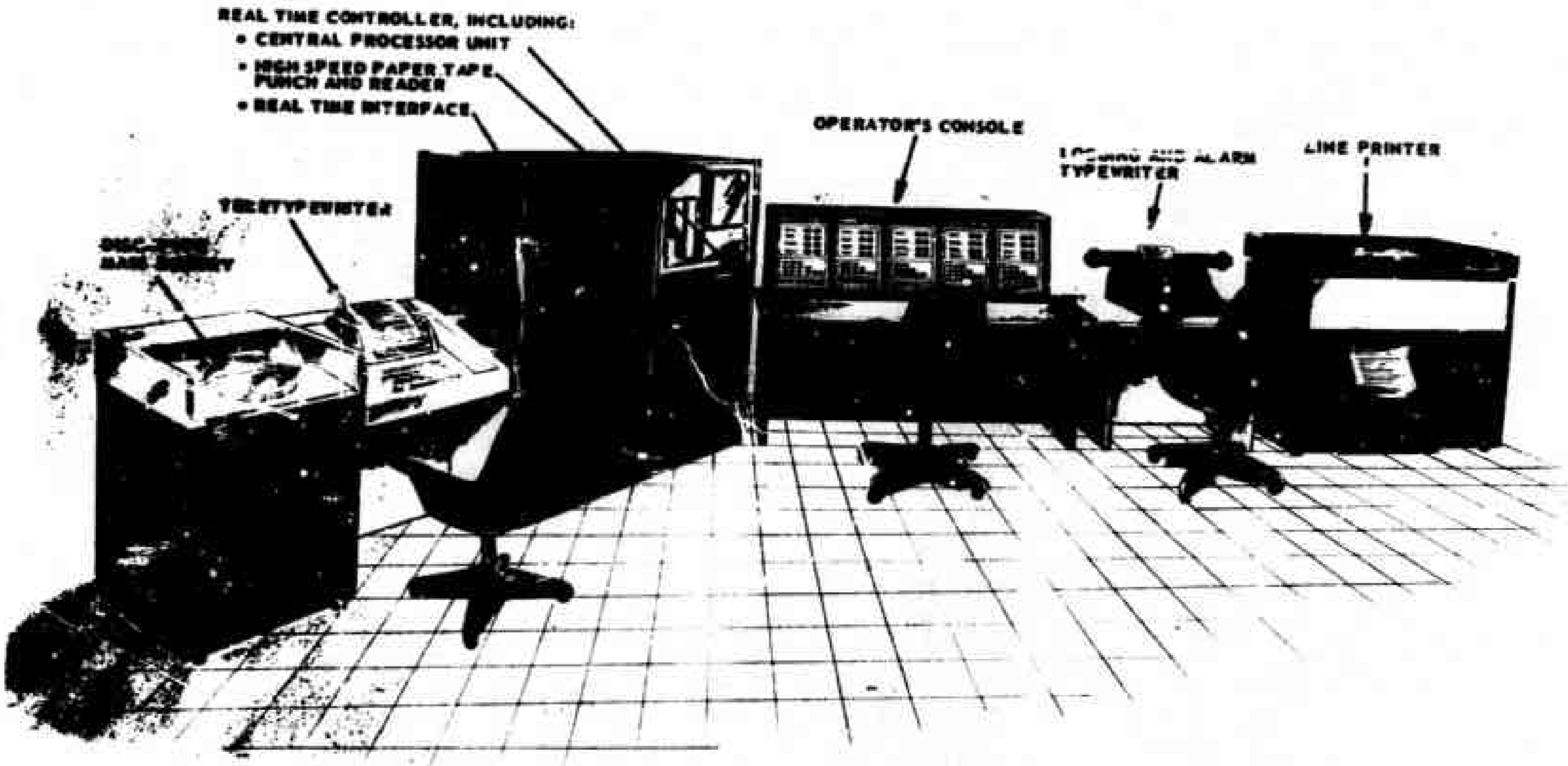


CHART 25 - PQCS QUALITY CONTROL SUBMODULE

SCAMP

- SAFETY
- HUMAN FACTORS ENGINEERING
- POLLUTION ABATEMENT

CHART 26 - SCAMP SAFETY

MODERNIZATION OF BOMB FILLING FACILITIES (NAD McALESTER)

James O. Gill and Gale A. Groh
Naval Ammunition Depot
McAlester, Oklahoma

(Figure 1) Good afternoon, ladies and gentlemen. The following presentation is a case study of the application of safety criteria to the modernization of the existing bomb loading plant at NAD McAlester, Oklahoma. It will be presented by myself, J. O. Gill, chief engineer for the project, and Mr. Gale A. Groh.

The safety criteria for this plant has basically been set by a Safety Review panel composed of Navy authorities. They have been analyzing proposed facility layouts, innovative features, and specific equipment during the development of the plant. This technique of continuous safety evaluation during the development stage has saved us a great deal of time and effort as compared to performing a formal safety review following development and then possibly making changes and having a reevaluation. This panel will continue to function until the plant is operational.

This address will be made from a production engineering point of view rather than a research point of view. Our aim is not necessarily to present something new, but to show how we are making use of safety criteria in new plant design. However, it became necessary to perform some experiments and these will be presented later. In modernizing this plant, we were given a number of design parameters. This slide (Figure 2) shows the significant ones which are as follows:

a. Utilize only proven or technically approved state-of-the-art processes.

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b. Procedures shall utilize existing specifications for processing.

c. The facility shall meet all recommended and approved safety criteria.

d. Utilize existing structures, utilities, and facilities to the maximum extent possible.

e. The facility design will assure a 50% total capability within a reasonable time following an accidental explosion.

The "A" plant at NAD McAlester is an existing cast explosives fill plant that has not been in use for 25 years. However, it is basically in a good, solid condition and quite usable.

The production criteria for the modernized plant is shown by Figure 3 to load the:

a. Mk 80 series and M117 bombs

b. With either Tritonal, H-6, or Minol II explosive

c. At a rate of 3,000 Mk 82 Tritonal bombs per 8 hours.

This presentation will highlight some of the safety problems encountered in meeting the design and production criteria and their solution.

Mr. Groh will now present some of the plant layout problems and solutions.

Good afternoon. I will try to give you a brief idea of how we are modernizing an existing facility to meet increased production requirements while keeping explosive concentrations at a minimum.

The McAlester bomb loading facility is a two line explosive loading complex radiating from a central casing preparation building. Each of the two lines shown in Figure 4 contains an explosive unloading and preparation building, an aluminum powder unloading and preparation building, an explosive melt and pour building, and a bomb finishing and

packing building. All buildings are of cast-in-place reinforced concrete frame and roof construction with a number of varied curtain wall types.

The first major problem we encountered was protecting the facility from the detonation of large concentrations of high explosives that are required to operate the plant at designed capacity. Utilizing the existing facility layout, the explosive quantities would appear as in Figure 5. The 50% production capability requirement would not allow severe damage to one production line if an explosive accident occurred in the other.

After examining the existing facilities according to NAVFAC Manual P-397 "Structures to resist the effects of accidental explosions," definite problems appeared. As shown in Figure 6, each case demonstrates production crippling damage to buildings outside of the line where the accident occurred. Structural failure would mean a collapse of a major portion of a building and structural damage would mean sufficient structural weakening to prevent safe operations without major repair. To reduce the quantities of high explosive available for detonation and therefore the damage potential, a policy of process separation was adopted. NAVFAC P-397 was used to determine the minimum separation distances and the live loads for new structures to insure plant integrity.

To prevent the collapse of the inert preparation building from overpressure generated by an accident in the explosive unloading complex, the explosive unloading building was moved 450 feet further from the main plant. Figure 7, Case A shows the original plan and the modified plan. The difference in damage potential is clearly shown in Case A-1.

To prevent the collapse of the inert preparation building from overpressure generated by an accident in the melt-pour building, the

existing inert building was replaced with a high strength concrete structure capable of withstanding 10-15 psi lateral loads while exposing occupants to a maximum of 5 psi. The original and revised damage diagrams are shown in Figure 8. Although it appears the 50% capability requirement is satisfied by the changes shown in Figures 7 and 8, the 250,000 pounds of explosive accumulated in the finishing building was broken up and separated to protect personnel. First, a separate explosive cap-off and bomb close-up building designed with a nonpropagating wall was added to isolate a potentially hazardous operation from the bulk of the in-process explosive. Second, a system of earth covered igloos was added to the east line for large bomb cooling in a protected area. The revised damage diagram is shown in Case C-1.

These cases are but a few of the major problems that have been encountered in modernizing the existing facility. Mr. Gill will give you an example of a material handling problem and its solution.

One of the innovative features of the plant is the use of a belt conveyor to move the explosive ingredients from the unloading building directly to the mix-melt kettle. This was necessary as we are moving 7 1/2 times as much explosive per day as the original plant was designed to handle.

This slide (Figure 10) depicts a comparison between the old and new conveying methods. As can be seen, the new system is enclosed and semi-automatically operated. The number of personnel required to almost double production is considerably reduced.

To utilize this method of conveying, it was necessary to perform some tests. As there was no existing experiments directly related to this operation, one of the tests was to determine at what depth the

explosive ingredients could safely be carried by the conveyor. That is, the critical depth at which a detonation would not be sustained. Several tests were conducted by the Naval Weapons Center China Lake. As shown by Figure 11, TNT, with or without aluminum powder, in all probability, would not sustain a detonation if it were less than 2 inches in depth. Comp B, with or without D-2 wax and aluminum powder, would probably not sustain a detonation even at a depth of 2 inches.

To prevent propagation along the belt should the critical depth be accidentally exceeded, we proposed spacing the explosive in approximately 50 foot increments where we would have 50 feet of the explosive ingredients and 50 feet of open space in sequence. Each increment would contain the proper proportion for 1/10 of a batch. For example, a tritonal proportion would be approximately 260 pounds of TNT and 65 pounds of aluminum powder. For this experiment, a full-sized mock up of the proposed conveyor and housing was constructed.

Three tests were conducted and we have a film that was prepared for us by NWC China Lake. The first of them as shown by Figure 12 involved using twice the proposed amount of explosive ingredients in each increment at a 2 inch depth with a 47 foot open space; this conveyor was 100 feet long and rose at a 5 1/2 degree angle. The second test, as shown by Figure 13, was a Comp B burn test using the proper explosive proportions as shown. The third test, as shown by Figure 14, is a dual conveyor test which would be representative of actual operations.

As you can see, the conveyors are 5 feet on center at their closest point and diverge on a 2 degree angle. They rise at a planned 5 1/2 degree angle. As you will see on the film, the far conveyor, top one on the slide, will be detonated. It is the same as the first experiment

except the open space has been reduced to about 24 feet, or 1/2 the planned space. The near conveyor, or the bottom one in Figure 14, contains 12 feet of open space; 26 1/2 feet of properly proportioned explosive ingredients one inch in depth, another 12 feet of open space, and another increment of properly proportioned explosive ingredients. For this test, all the aluminum powder was placed in the first 13 1/2 feet.

With this in mind, we will now run the film. (This film is approximately 4 1/2 minutes in length.)

Figure 15 is of the witness plate. The center depression was caused by the first test, the depression on the left by the third test. As you can see, the right side is not depressed. The one inch thick increment did not detonate. These tests have proved the feasibility of safely conveying bulk explosives by belt conveyor.

Figure 16 shows some of the other innovative features to be included in the modernized plant. Each has required extensive investigation prior to being included in the plant scheme.

In closing, this last slide, Figure 17, presents an artist's concept of the finished plant.

MODERNIZATION
OF
CAST HIGH EXPLOSIVES
FILL PLANT
NAD McALESTER

FIGURE I

DESIGN PARAMETERS

- UTILIZE PROVEN OR TECHNICALLY APPROVED STATE-OF-THE-ART PROCESSES
- UTILIZE EXISTING SPECIFICATIONS FOR PROCESSING
- MEET ALL RECOMMENDED AND APPROVED SAFETY CRITERIA
- UTILIZE EXISTING STRUCTURES, UTILITIES, & FACILITIES TO THE MAXIMUM EXTENT
- DESIGN MUST ASSURE A 50% TOTAL CAPABILITY WITHIN A REASONABLE TIME FOLLOWING AN ACCIDENTAL EXPLOSION

Figure 2

PRODUCTION CRITERIA

ITEM	MK 80 SERIES AND M117
EXPLOSIVE	TRITONAL - H-6 - MINOL II
RATE	3,000 MK 82, TRITONAL LOADED BOMBS PER 8 HOURS

Figure 3

ORIGINAL FILL PLANT SCHEME

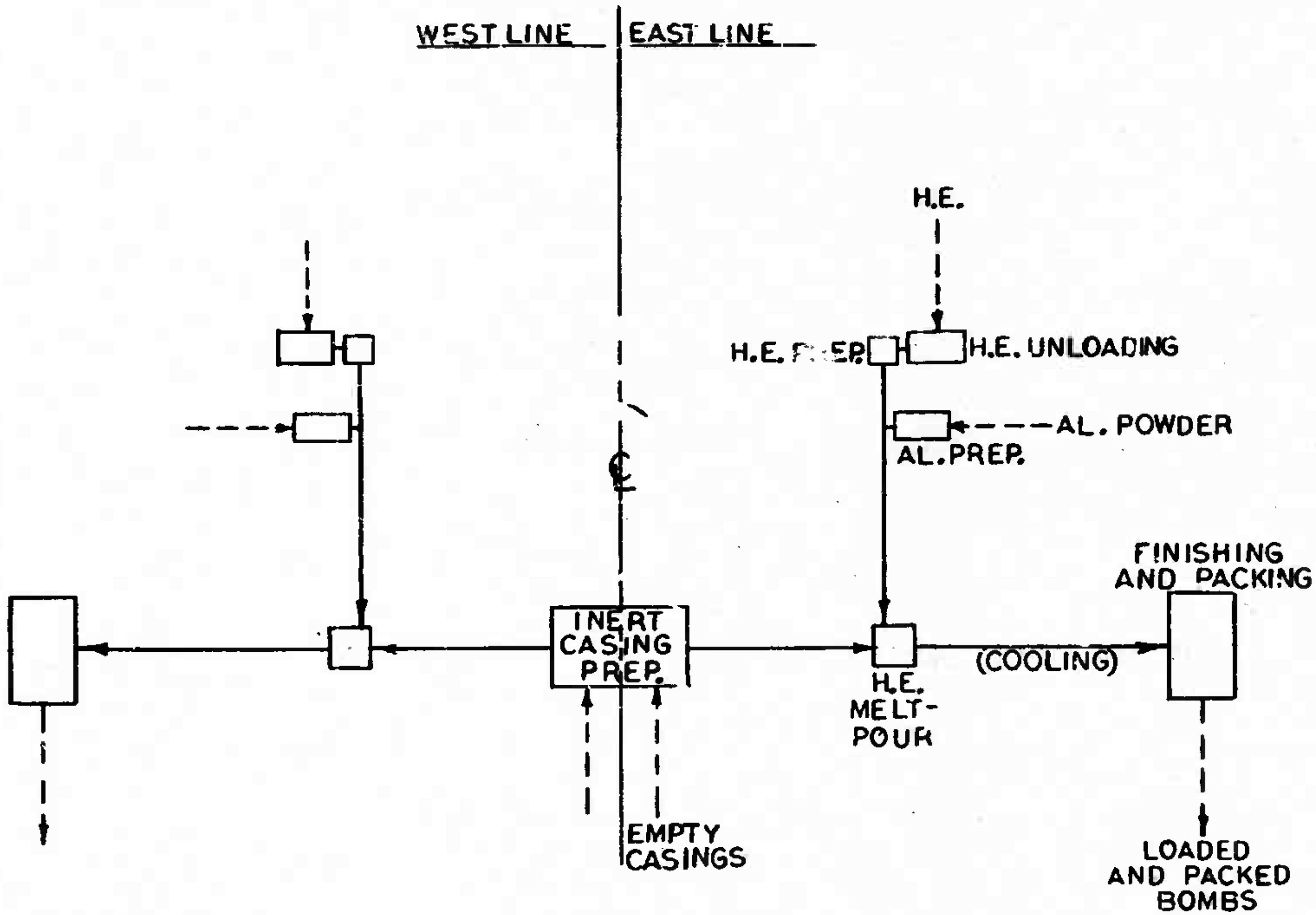
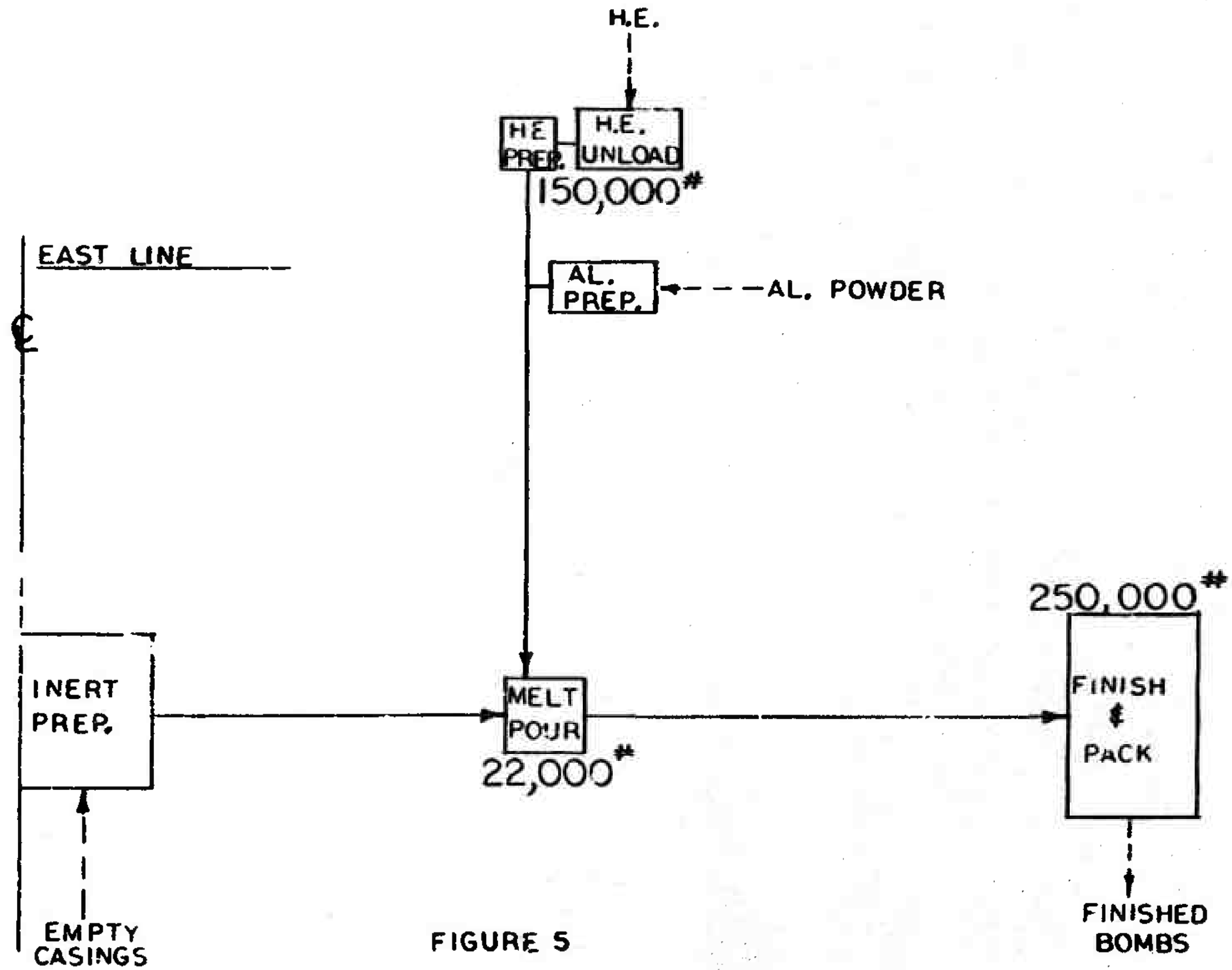
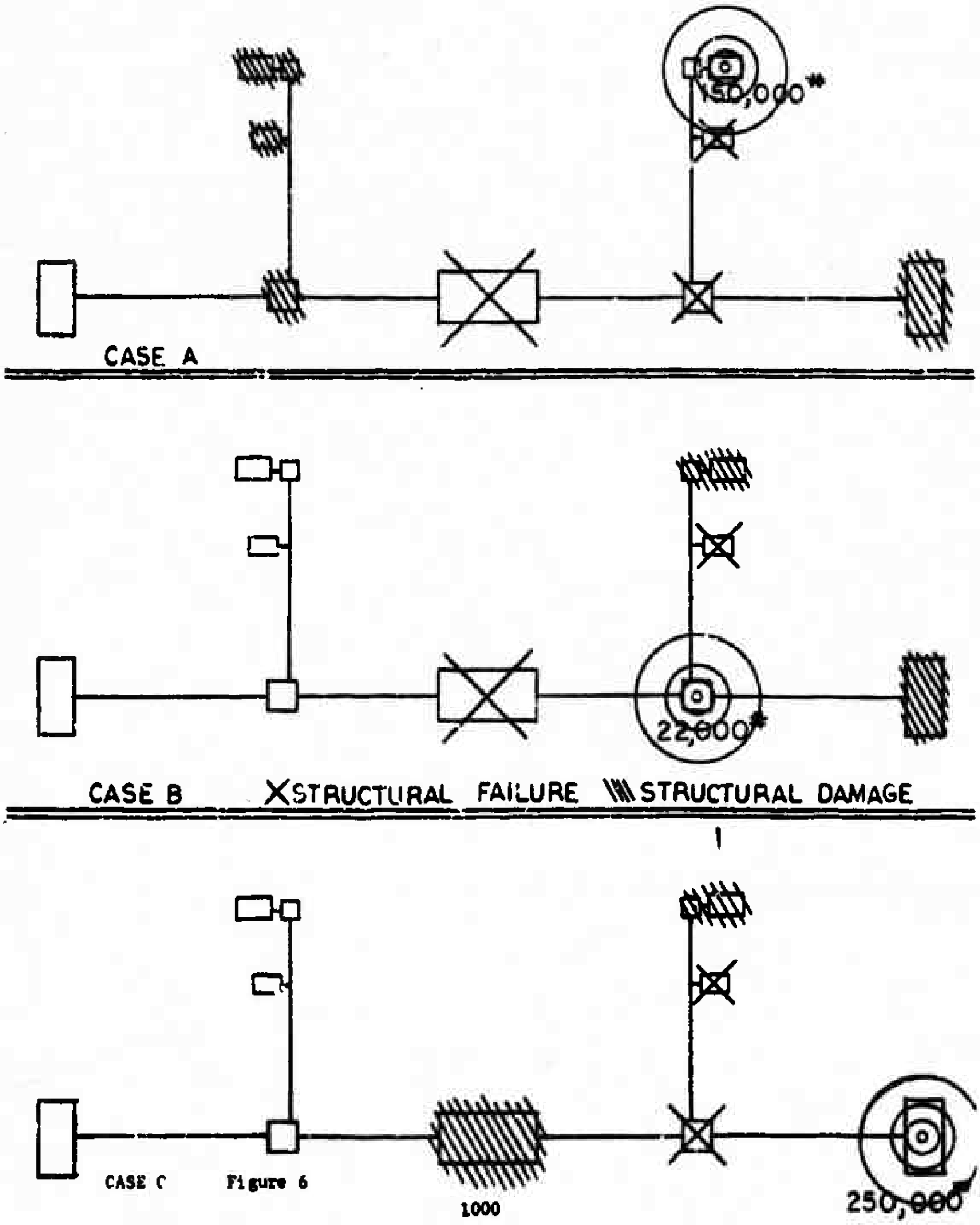


FIGURE 4



H.E.
H.E. PREP.
H.E. UNLOAD
150,000#
EAST LINE
AL. PREP.
AL. POWDER
INERT PREP.
MELT POUR
22,000#
250,000#
FINISH & PACK
EMPTY CASINGS
FINISHED BOMBS

FIGURE 5


150,000*
CASE A
22,000*
CASE B
X STRUCTURAL FAILURE
STRUCTURAL DAMAGE
CASE C
1000
250,000
Figure 6

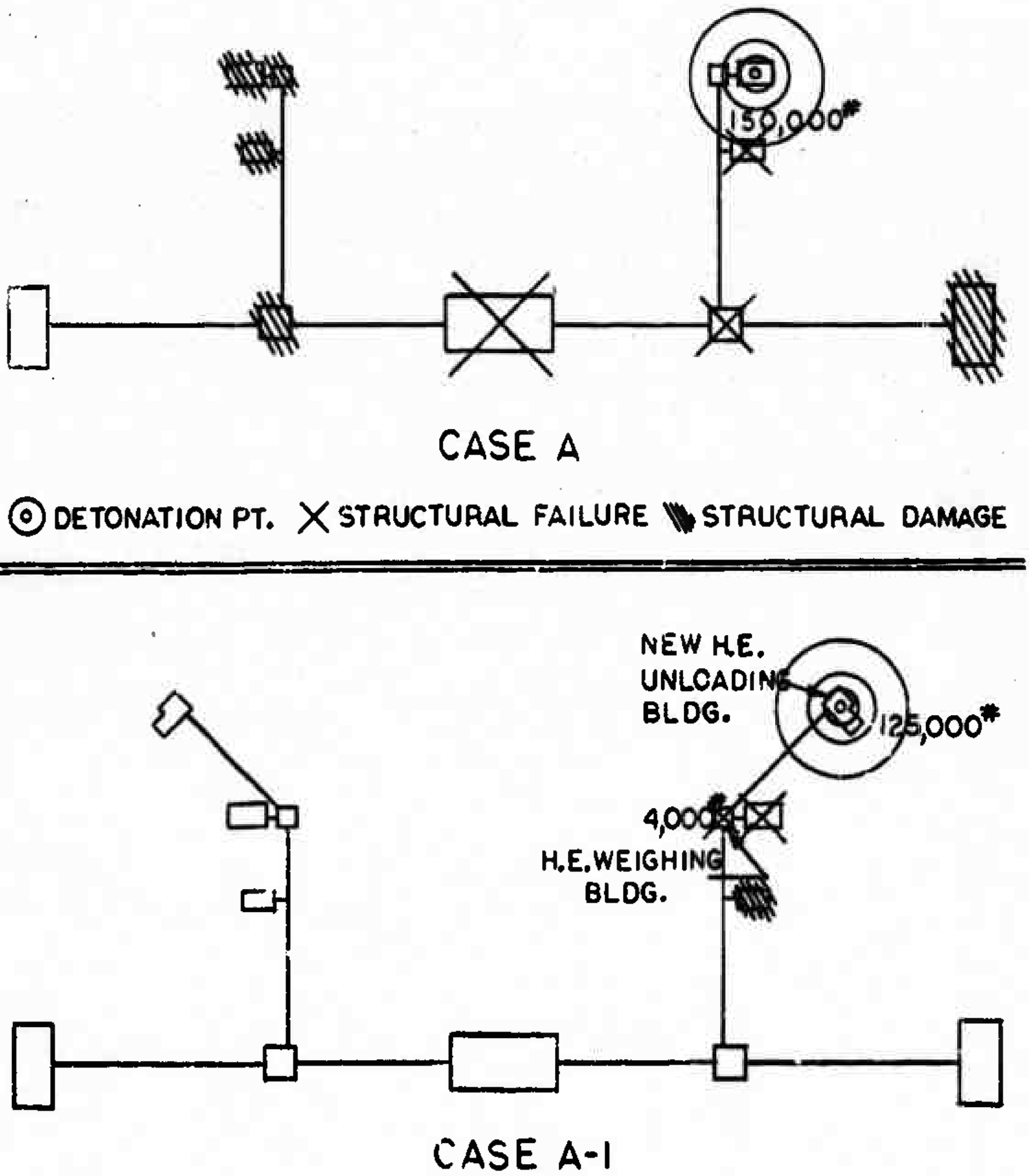
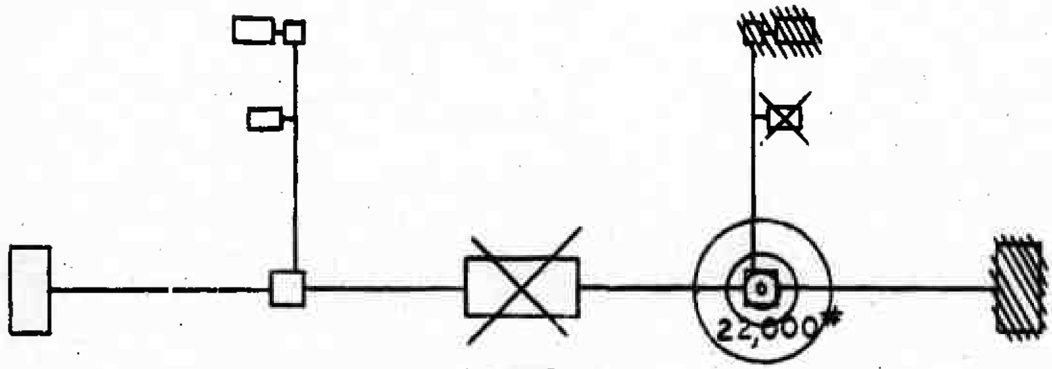
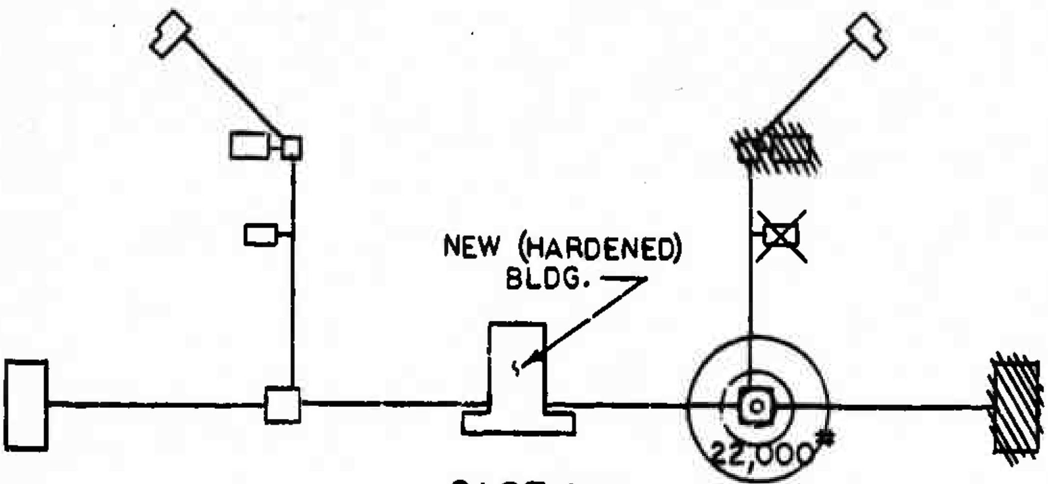

150,000#
CASE A
DETONATION PT.
STRUCTURAL FAILURE
STRUCTURAL DAMAGE
NEW H.E.
UNLOADING
BLDG.
125,000#
4,000#
H.E. WEIGHING
BLDG.
CASE A-1

FIGURE 7



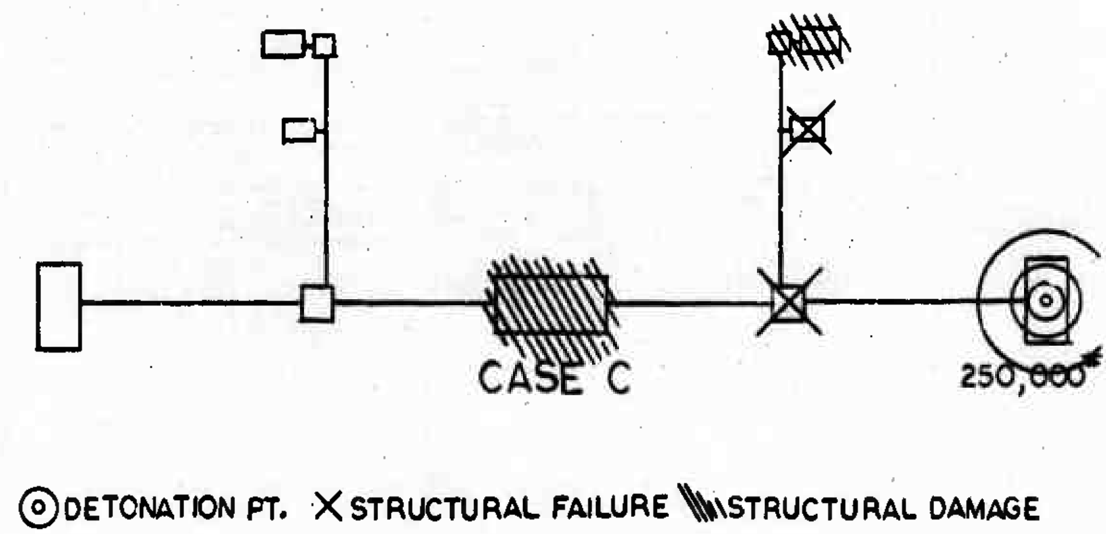
CASE B

DETONATION PT. ✕ STRUCTURAL FAILURE ⧹⧹⧹ STRUCTURAL DAMAGE



CASE B-1

FIGURE 8


CASE C
250,000#
DETONATION PT.
STRUCTURAL FAILURE
STRUCTURAL DAMAGE

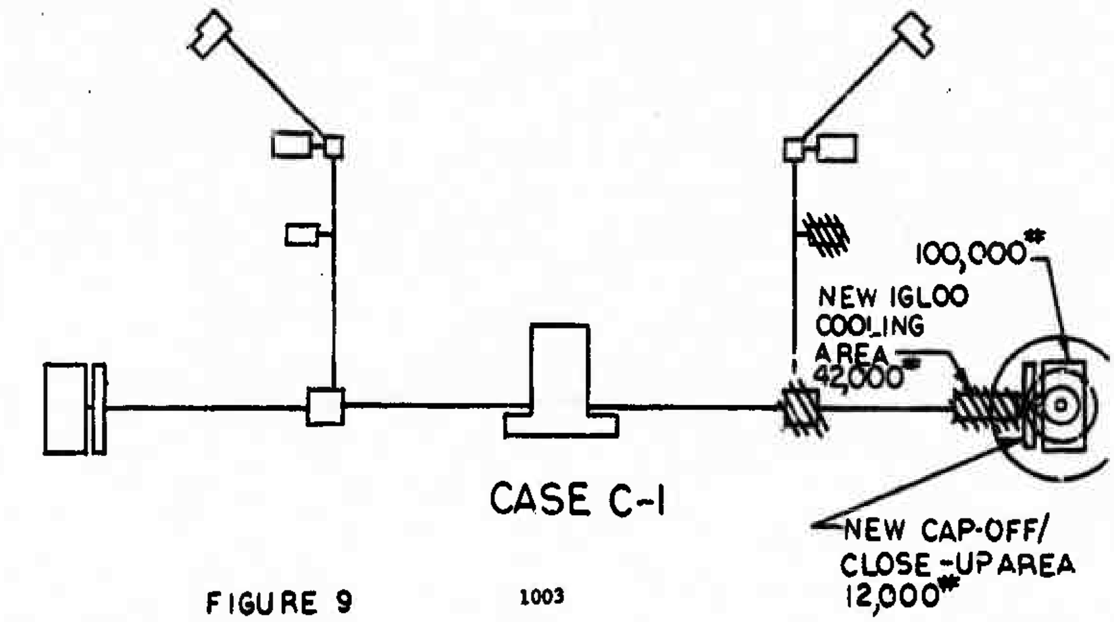

100,000#
NEW IGLOO COOLING AREA 42,000#
CASE C-1
NEW CAP-OFF/ CLOSE-UP AREA 12,000#

FIGURE 9

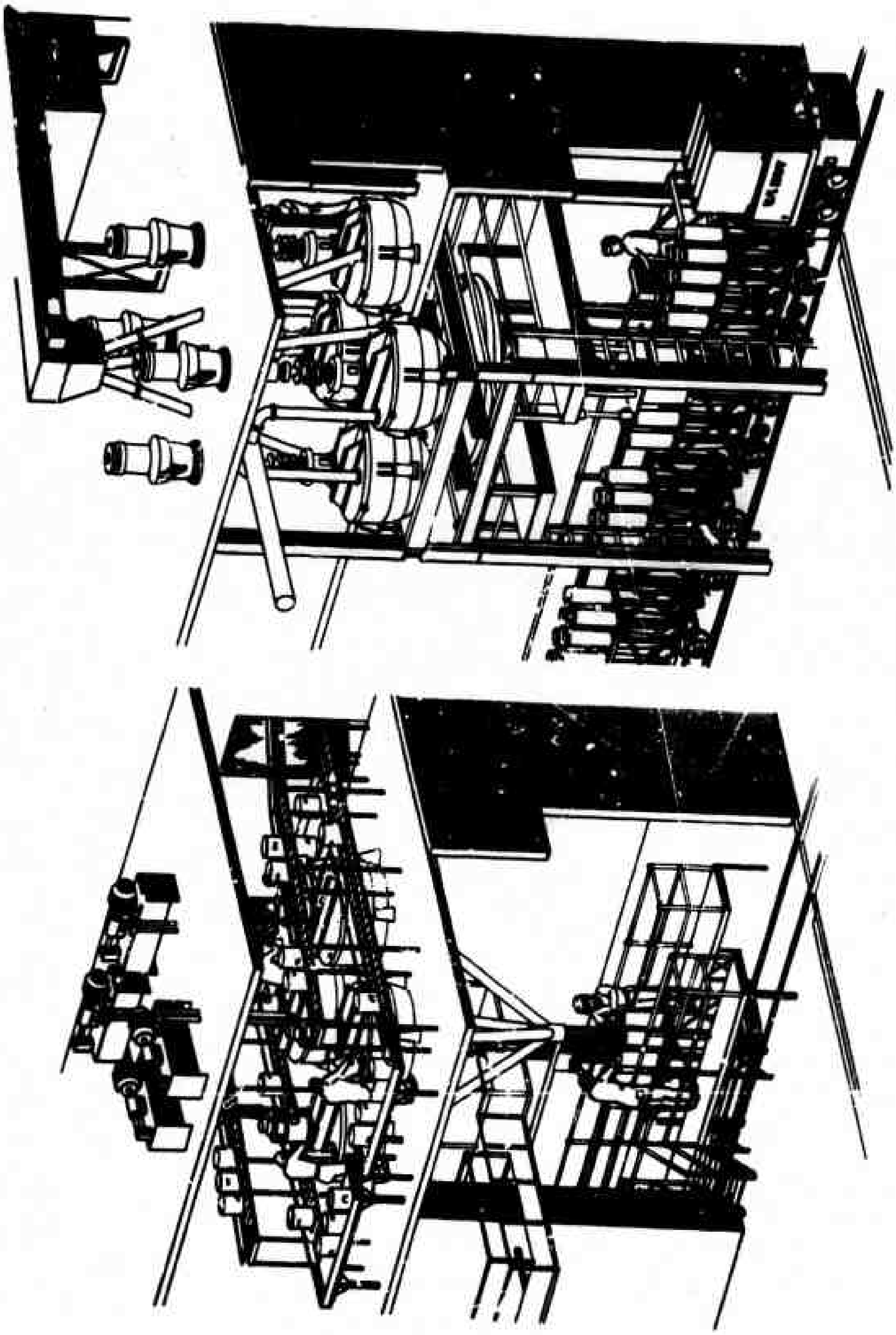


FIGURE 10

CRITICAL DEPTH TESTS

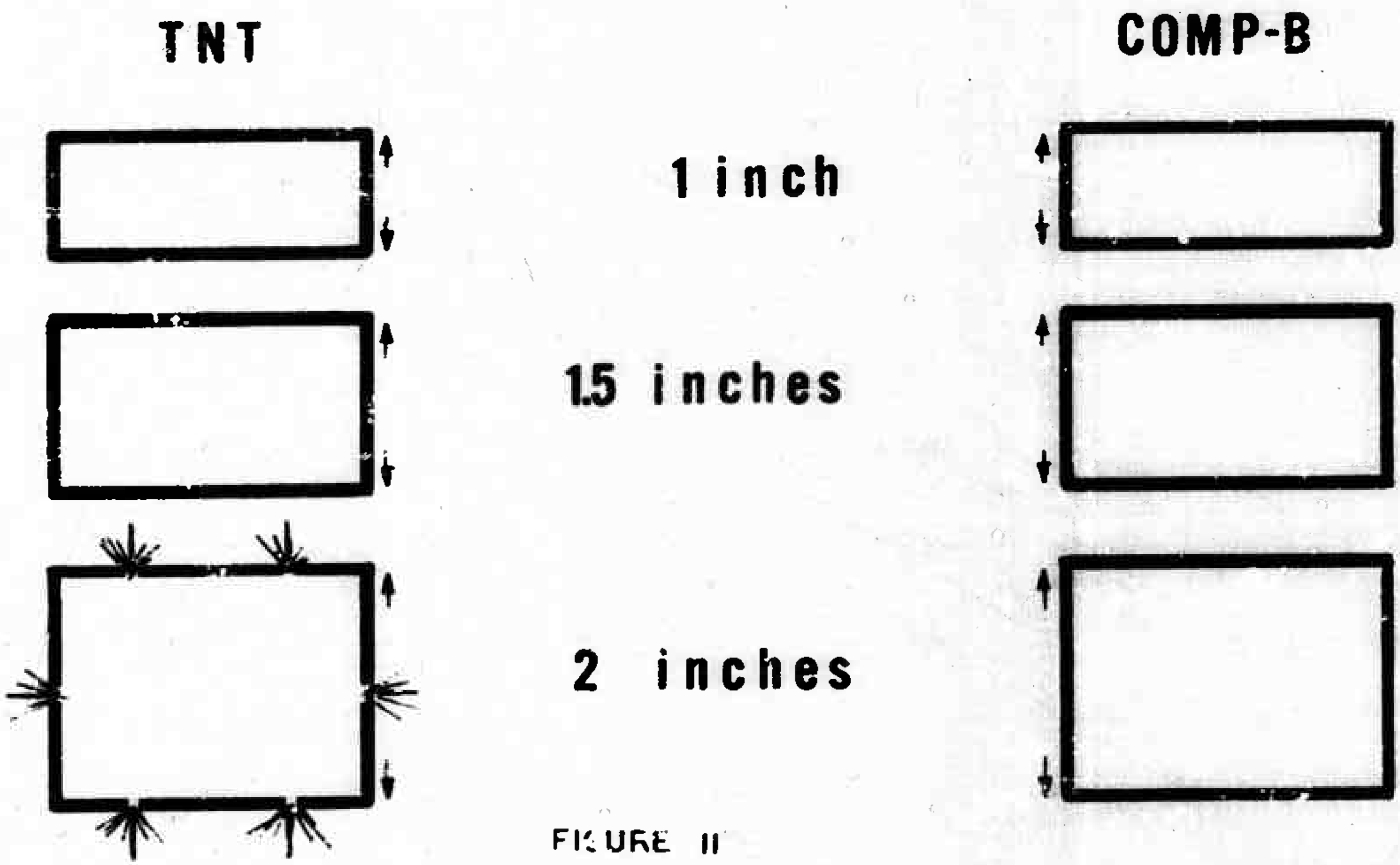


FIGURE 11

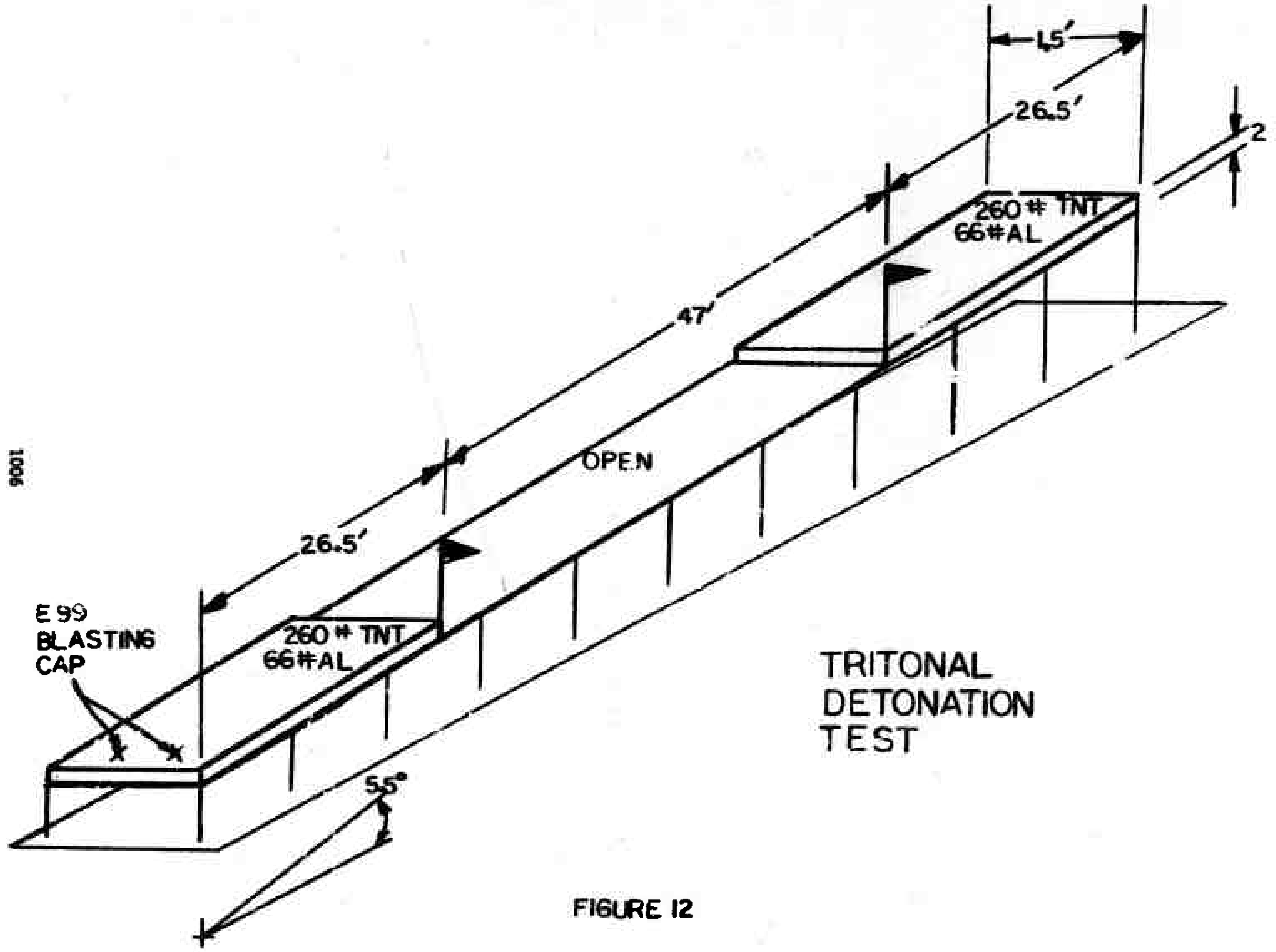
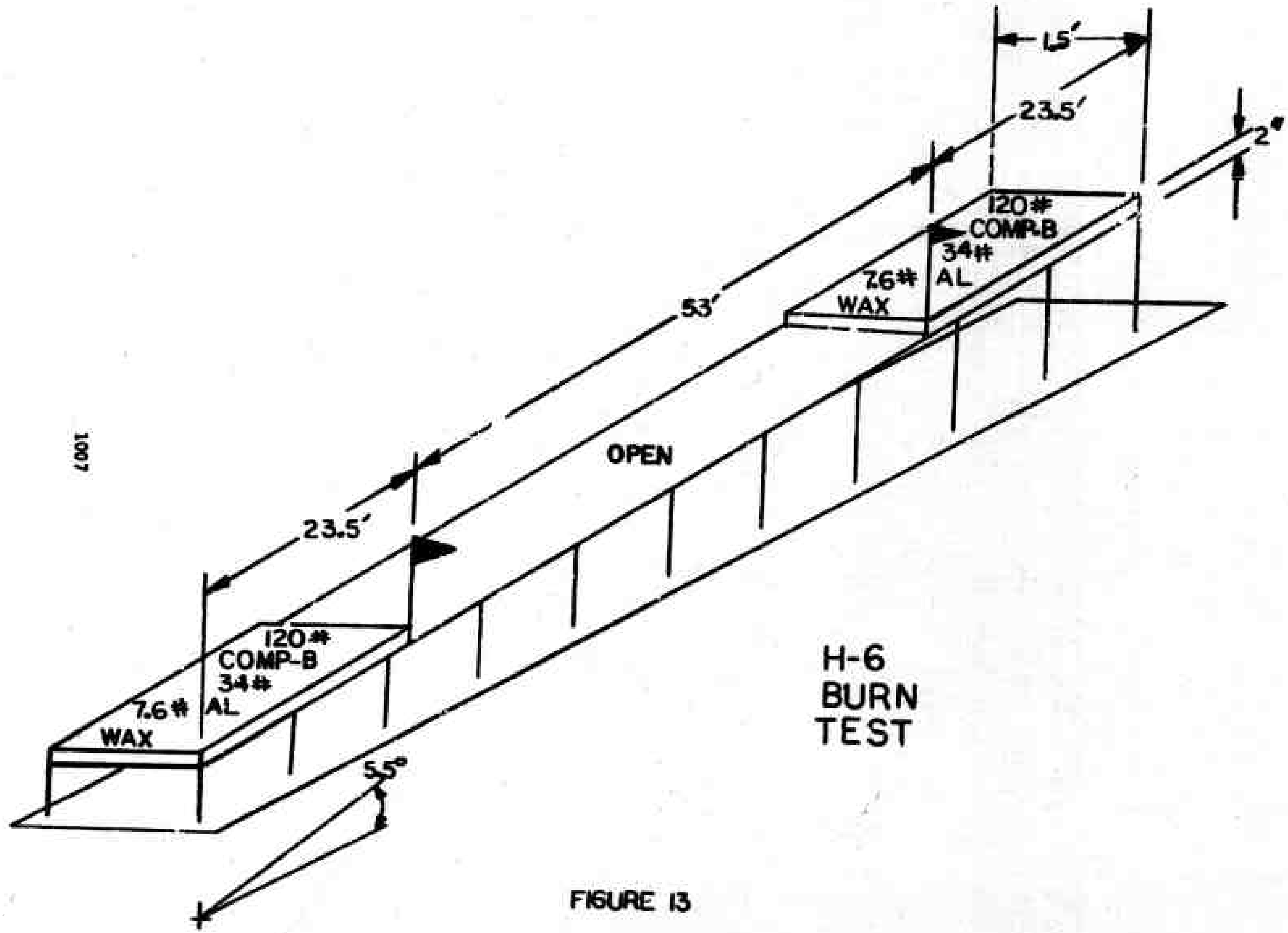

1.5'
26.5'
2
260 # TNT
66#AL
47'
OPEN
26.5'
E 99
BLASTING
CAP
260 # TNT
66#AL
5.5°
TRITONAL
DETONATION
TEST

FIGURE 12



H-6
BURN
TEST

FIGURE 13

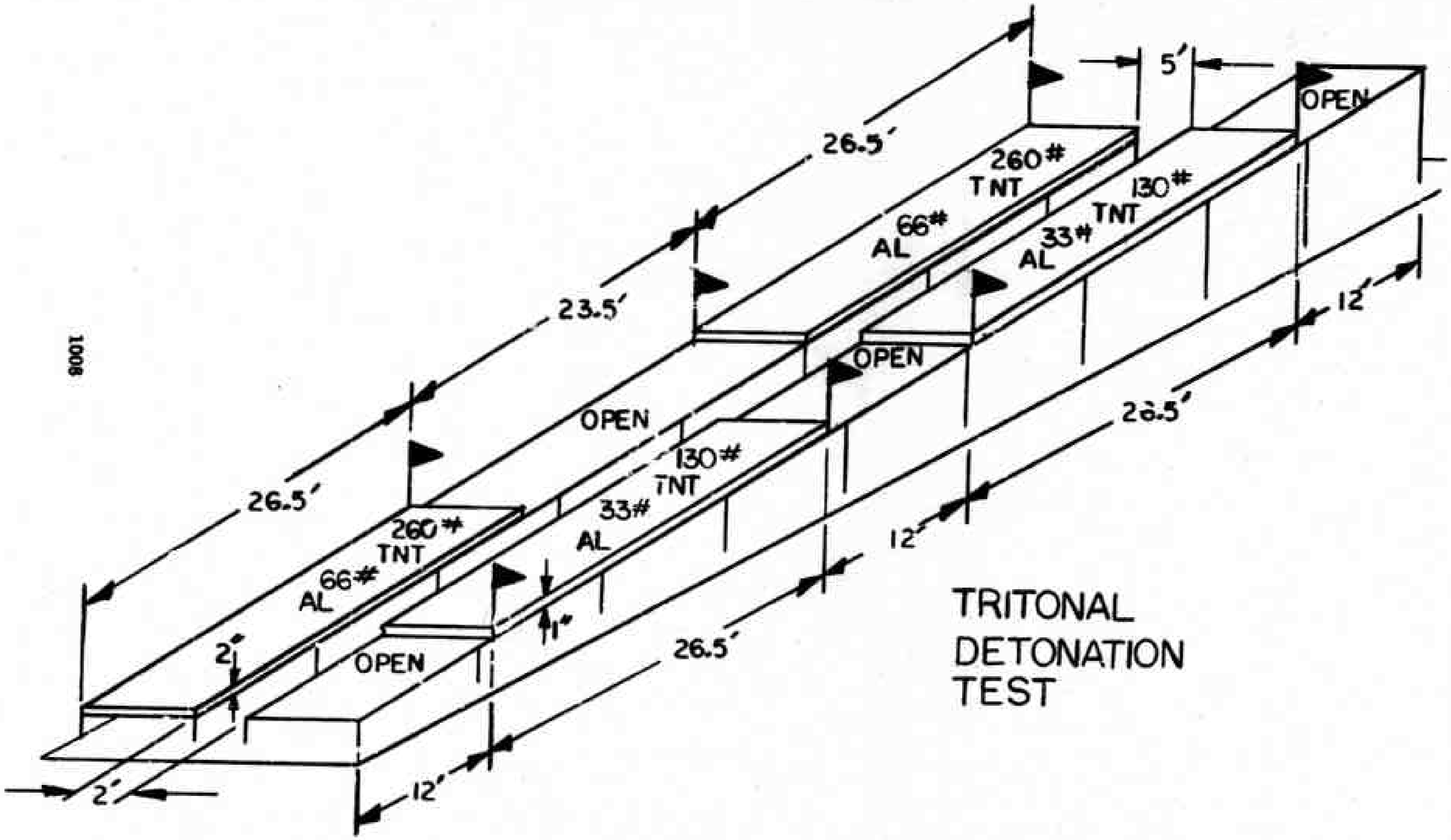
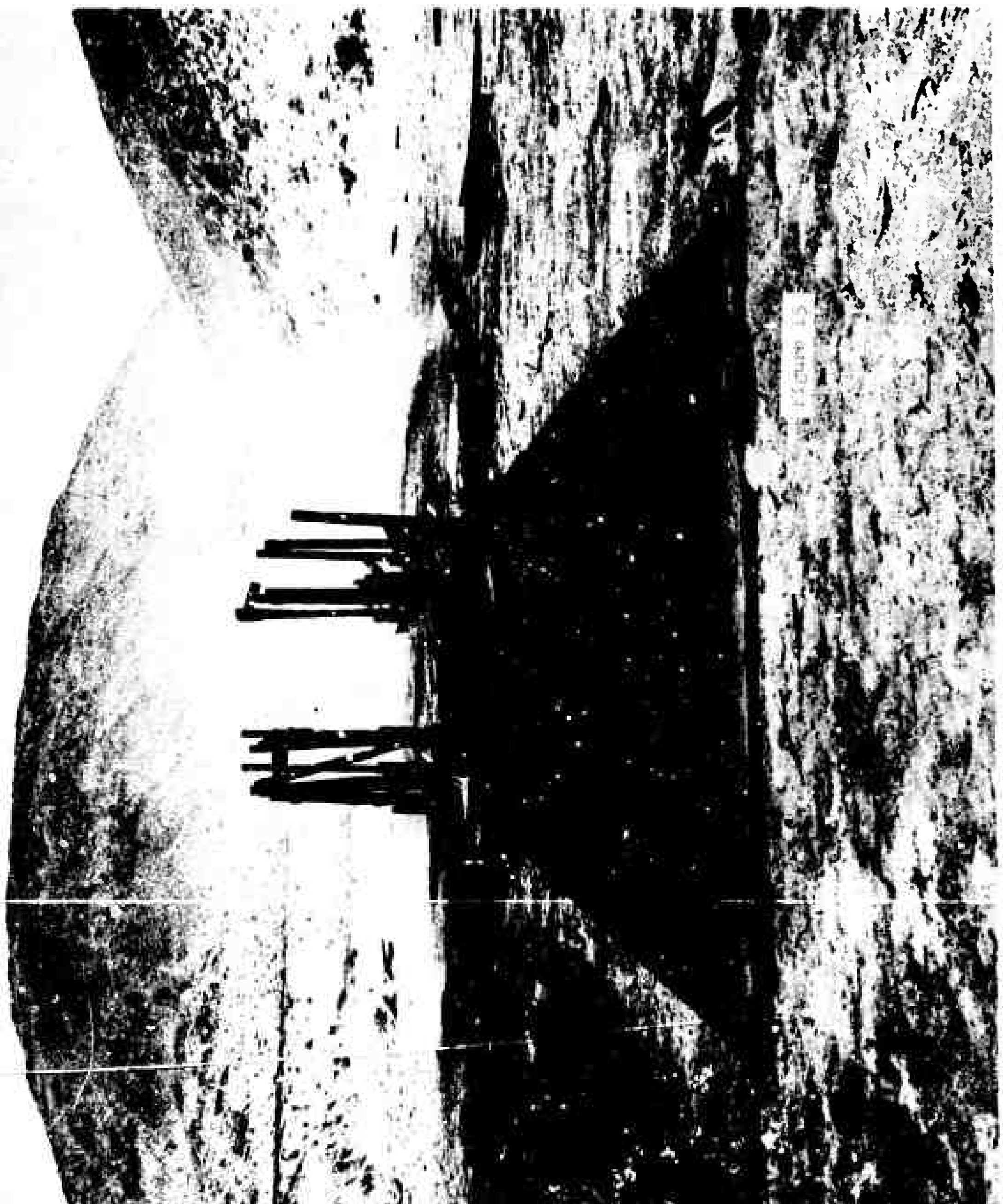

26.5'
23.5'
26.5'
5'
OPEN
260#
TNT
66#
AL
130#
TNT
33#
AL
OPEN
OPEN
130#
TNT
33#
AL
260#
TNT
66#
AL
OPEN
2"
1"
2'
12'
26.5'
12'
26.5'
12'
TRITONAL
DETONATION
TEST

FIGURE 14



INNOVATIVE FEATURES

- BATCH FEED OF EXPLOSIVE COMPONENT
- VOLUMETRIC EXPLOSIVE FILL
- ELECTRIC LOCOMOTIVE AND CART SYSTEM
- COMPUTER CONTROLLED EXPLOSIVE MELT KETTLE LOADING
- CENTRAL CONTROL AND DATA COLLECTION
- BULK EXPLOSIVE HANDLING
  BULK ALUMINUM HANDLING
  BULK ASPHALT HANDLING
- PUMP-IN AND PUMP-OUT OF ASPHALT HOT MELT

Figure 16

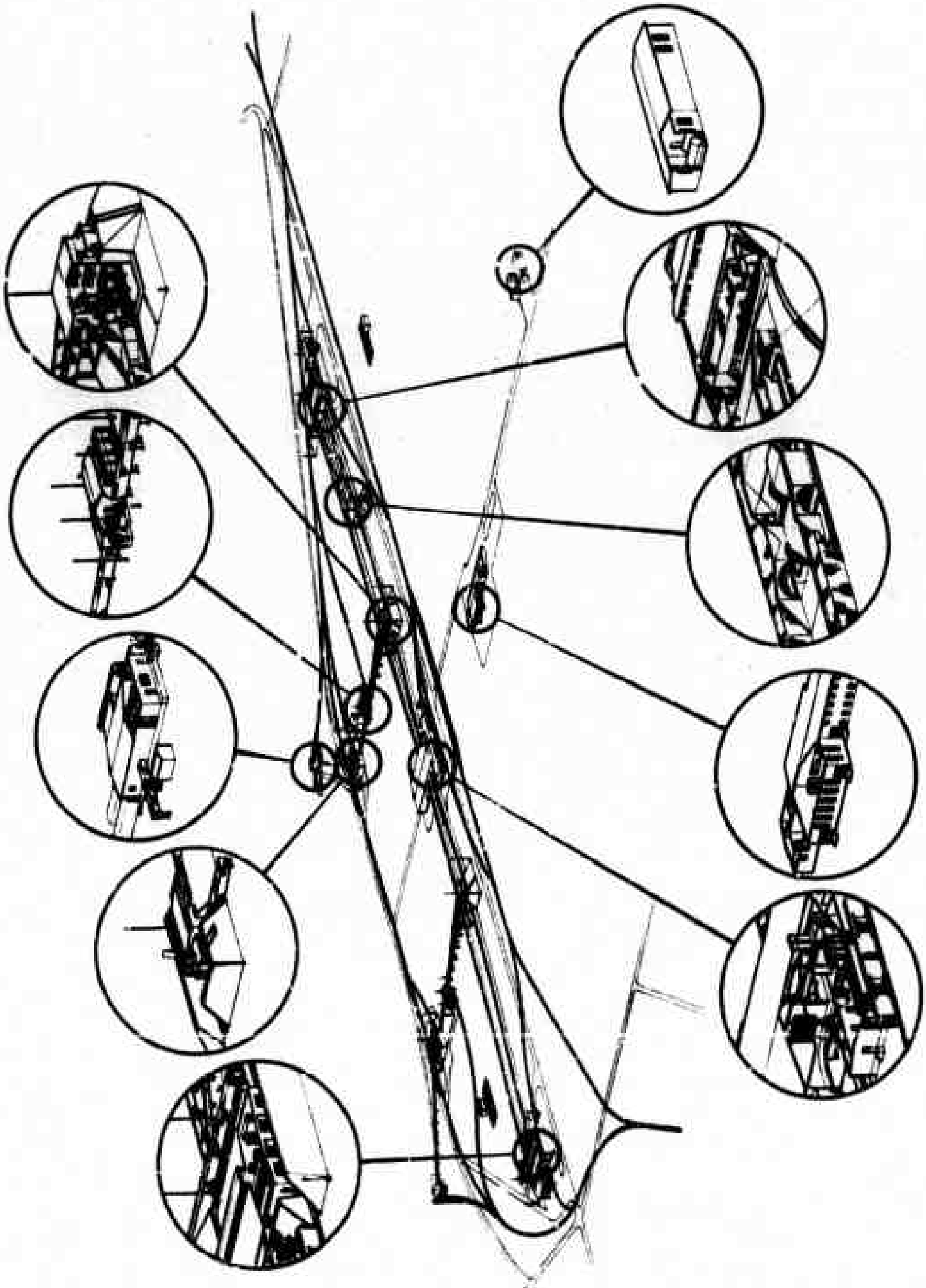


FIGURE 17

APPROVED SAFETY CONCEPTS FOR USE IN
MODERNIZATION OF USAMUCOM INSTALLATIONS

Irving Forsten and Robert Parker
Picatinny Arsenal
Dover, N. J.

INTRODUCTION

The safety concepts presented in this paper were developed as a part of a program entitled, "Safety Engineering in Support of Ammunition Plants" under the guidance of Manufacturing Technology Directorate, Picatinny Arsenal for use in facility siting and structure layouts developed in connection with the modernization of USAMUCOM explosive manufacturing and LAP installations. The use of these concepts is considered as essential in new facilities designs and major improvements of existing MUCOM installations.

These safety concepts can apply to all USAMUCOM installations and activities and have been approved by both the U.S. Army Materiel Command and the Department of Defense Explosives Safety Board.

Each concept is a single entity within itself but may, at any time, be modified and/or supplemented.

In the beginning of the modernization program it was essential to establish necessary clarification or modification of and addition to AMCR 385-100 for use during concept formulations, engineering development and final design of USAMUCOM installations and activities including new facilities, renovation, rework, demilitarization and disposal.

U.S. Army Munition Command (USAMUCOM) is presently participating in an Army-wide modernization program of explosive manufacturing facilities under its command. This program is primarily directed towards a more efficient and safer production of explosive munitions.

Regarding the safety aspects, submission of safety criteria by several USAMUCOM facilities has shown a wide variation in modernized safety concepts when applied to a similar type of explosive facilities. Therefore, at the request of USAMUCOM, Picatinny Arsenal has undertaken a study to develop "approved safety concepts" to achieve uniformity of safety criteria application.

DISCUSSION

The following discussion will cover four main areas of explosive facility design for which new and improved safety concepts have been developed. These include:

1. Effective Barricading of Building.
2. Explosive Collection Facilities.
3. Transfer of Explosives through Buildings.
4. Transfer of Explosives between Buildings.

Examples of application of these concepts in a given facility design will be presented later in this Seminar by Mr. Dobbs of Ammann & Whitney in his paper, "Application of New Safety Criteria in Explosive Manufacturing Facilities Design".

EFFECTIVE BARRICADING OF BUILDINGS

In order that two adjoining buildings be separated by a barricaded intraline distance, the buildings must be provided with an effective barricade or a combination of effective barricades. Three means are available to satisfy this objective namely, (1) effective dividing walls, (2) effective earth barricades, and (3) structure burial. In the next three figures we will describe three barricading arrangements each of which is applicable for use as dividing wall barricades and as earth reverted barricades. The below-grade barricade will be described separately.

BARRICADE ARRANGEMENT TYPE NO. 1, FIGURE 1.

When the quantity of explosive in Building "A" is approximately equal to that of Building "B" then the wall of each building facing the other building shall be barricaded.

Where an earth barricade is used, the barricade shall be single revetted and shall have a configuration as illustrated. Here the top of the barricade shall extend above the top of the building it is protecting to a height defined by the Line of Sight No. 2 which forms an angle of 2 degrees with the Line of Sight No. 1 (line connecting the two buildings). This extension is to protect the acceptor building from the effect of low flying fragments produced by an explosion. Also the single revetted barricade shall extend 3 feet beyond the line joining the two structures. Unlike the previous criteria for effective barricade the barricades to be used in new construction may be positioned no further away from the building than by a distance equal to H/4 where H is the building height or 4 feet which ever is the smaller of the two distances.

An effective dividing wall shall be constructed of reinforced concrete and/or structural steel in accordance with the design manual "Structures to Resist the Effects of Accidental Explosions" (TM5-1300). Each wall shall be designed to resist the blast effects of a detonation within the building it is protecting as well as the blast and fragments produced by an explosion in the adjoining building and the response of the wall shall conform to incipient failure deflections.

BARRICADE ARRANGEMENT TYPE NO. 2, FIGURE 2.

If the quantity of explosive in one building (Building "A") is substantially larger than the explosive quantity in an adjoining building (Building "B"), then the two buildings shall be separated by a barricaded intraline distance based upon the larger of the two explosive quantities. However, the wall of Building "B" facing Building "A" shall be designed as an effective barricade (single revetted or dividing wall) while the wall of Building "A" facing the Building "B" may be designed for conventional loading (non blast resistant). The construction of this barricade is similar to that described for Arrangement No. 1. For this arrangement to be applicable, the unbarricaded intraline distance based upon the smaller explosive quantity must be equal to or less than the barricaded distance for the larger explosive quantity.

BARRICADE ARRANGEMENT TYPE NO. 3, FIGURE 3.

The third barricade arrangement is similar to Arrangement No. 2, however, in this arrangement one of the structures contains inert material. Here, the barricade must be located at the inert material building with the separation between the two structures conforming to barricaded intraline distance based upon the explosive quantity in Building "A". It may be noted that as in Arrangement No. 2, positioning of the barricade at the building containing the explosive is not considered as an effective barricade.

In this figure, we have illustrated the requirement for the height of an effective barricade when the building containing the explosive is higher than the inert material building. Here, the barricade height shall be equal to the greater of the following two distances (1) 3 feet above the point where the line of sight between the top of each building passes through the barricade, or (2) as defined by the line of Sight No. 2. The height requirements for barricades are applicable to both the revetted and the dividing wall barricades.

TYPE OF EFFECTIVE EARTH BARRICADE, FIGURE 4.

As previously mentioned, new construction of earth barricades shall utilize the single revetted concept. Existing double revetted and earth-mound barricades shall be replaced during the new construction, major facility modifications, or as they need replacement. Existing earth-mound barricades may be altered to form single revetted barricades. A possible means for accomplishing this alteration is illustrated in this slide. Here, conventional steel piling or other structurally sound material can be used to support the new earth fill which is used to level one side of the earth-mound. It should be noted that the new or existing building would have to be positioned no further away from the modified barrier than distance equal to one fourth the building height.

T - BARRICADES, FIGURE 5.

T-Barricades shall be used in the bulk receiving and/or shipping portion of a facility for separation of explosive quantities not to exceed 50,000 pounds. The separation distance between the explosives at opposite sides of the barricade shall be equal to 1.1 times the cube root of the larger of the two explosive quantities.

In all new constructions, the base of a T-Barricade shall be at least 19 feet wide. Each side of the barricade shall have a slope of 5 on 2 for a barricade height up to 20 feet. For barricades higher than 20 feet, the width at the top of the barricade shall be equal to 3 feet. The top of the barricade shall extend at least 6 feet above the top of the highest stack of explosives and/or shall meet the 2 degrees requirement of the line of sight described for single revetted barricades.

BELOW - GRADE STRUCTURES, FIGURE 6.

Building positioned fully or partially below the grade may be separated from adjoining below and/or above-ground buildings by barricaded intraline distances when all of the explosive within the below grade structure is located (1) below the ground surface (arrangement 1), (2) below the top of the mound of a partly buried, partly earth-mounded structure (arrangement 2), or (3) when the above-ground portion of the explosive in a partly above and partly below ground building is protected by TM5-1300 walls. For a fully or partially below-grade structure to be fully effective as a barricade, as previously shown by figure 1, the explosive must be positioned below the top of the building based upon the Line of Sight No. 2 (2 degree angles for low flying fragments) as described for above-ground earth and dividing wall barricades.

Use of fully or partially below-grade structures have been approved for those situations where neither people nor expensive (long lead) equipment is located in the unprotected above-ground portion of the structure.

VACUUM COLLECTORS IN OPERATING BUILDINGS, FIGURE 7.

The portable wet and dry collectors shall be located within operating buildings in accordance with the requirements of Section 27-7c of AMCR 385-100. However, a maximum accumulation of the explosive within any one collector shall not exceed 5 pounds. Any one collector shall service only one operating bay. A collector may be located in the operating bay it is serving without any special protection or in a separate bay. Dry collector shall always be positioned in a separate bay. Collector bays shall not be used for other operations or as a communicating corridor or a passageway. Each collector bay shall be enclosed by three walls which shall extend 2 feet beyond the exterior of the operating buildings roof and/or walls. If a blast resistent roof is provided for the collector bay, then the walls of the bay need not penetrate the operating building's roof. Lines carrying explosive waste between a collector bay and the operating bay shall be provided with detonation traps or other positive means to prevent a propagation of explosion between the bays.

VACUUM COLLECTORS IN COLLECTOR BUILDINGS, FIGURE 8.

Each wet or dry collector containing more than 5 pounds of H.E. shall be positioned in a separate building which shall be separated from the operating building it is serving by a barricaded intraline distance based upon the quantity of explosive in the collector building. Separation between the collector building and an adjoining operation building not serviced by the collector building, shall conform to an intraline distance based upon the quantity of explosive in the operating building.

VACUUM COLLECTOR BUILDINGS, FIGURE 9.

A vacuum collector building shall not serve more than one operating building. A primary collector shall serve only one area within the operating building. Each wet or dry collector shall be positioned in separate bays. A secondary collector shall not serve more than two primary collectors. Collector bays shall be separated from one another and from the operating building they are serving by effective dividing walls each of which shall be designed to resist the effects of an explosion within the collector building.

In addition to collector buildings Pollution Abatement Processing Facility may be needed for explosive waste collection. An abatement facility may be used to serve more than one vacuum collector building and more than one operating building. However, an abatement facility must be separated from all other buildings by intraline distances.

All waste lines serving either collector buildings or abatement facilities shall be provided with detonation traps or other positive means to prevent propagation of explosion between buildings and/or operations.

TRANSFER OF EXPLOSIVES THROUGH BUILDINGS, FIGURE 10.

The method used for transferring explosives through operating buildings will depend upon several factors including (1) building subdivision, (2) operational hazards and (3) the methods used for conveying the explosives. Subdivision of the building will be a function of operational considerations and quantity separation distance requirements while operational hazards depending on the process selection must be established by hazard analysis. The third factor or conveyance method will be a function of the first two factors as well as the method used for inter-bay transfer of explosives.

Subdivision of buildings for operational and/or quantity-distance requirements may be achieved with the use of dividing walls; which shall be designed in accordance with TM5-1300.

For most operational buildings, the hazard of the individual operations contained therein may be placed into one of three hazard categories; each of which has certain safety requirements as follows:

Hazard Category I: No special provision for spacing and/or shielding of items within an operating bay. However, dividing walls separating Hazard Category I operation bays from adjoining bays shall be designed to prevent a direct line of sight (as discussed later).

Hezerd Category II: In addition to requirements of dividing walls similar to Category I, Hazard C. cegory II operations also raquire that individual items or cluster of items be aeperated by safe spacing and/or shielding to negete explosive propagation within the bay.

Hazard Category III: Items pessing through areas containing Hazsrd Category III oparations shall be provided with apecial shielding to provide full protaction for personnel and equipment exterior of the shield. The protection ahield may be used for explosive quantities es lsrgs as 15 pounds of H.E. and may be located in areas containing lass hezardous operations. Where s Hazsrd Category III operetion contains more than 15 pounds of explosive then it should be moved to a apecial building. Hazard Category III operations, either in a shiald or in a seperats building, shell be parformed remotely.

HAZARD CATEGORY III SHIELD, FIGURE 11.

Hazsrd Category III shield may be constructed either of reinforced concrete and/or structural stael. The shield must be desigmsd to resist both fragments and blest effects of an explosion within. Internal blast pressures shall be vanted to the atmosphere through a varting stack with diameter equal to or less than 15 inches and the stack extending at least 15 feat above the highest point on the operating building roof or 15 feet beyond the exterior walls. Access into the shiald by explosives, personnel and equipment shsll be through a series of blast doors which shall be closed snd sealed during the performanca of the hazsrdous operation.

INTER BAY ITEM TRANSFER, FIGURE 12.

Movement of explosive items from one opsrating bsy to another will require the movement of items ovsr, sround and/or through the protective barriera. To prsvent e propegetion of explosion between adjoining operating baya, all openings in the dividing wall shsll be so arranged thst a direct line of sight through the openings will be interrupted. Also, in the case of trensferring explosives sround and/or over the walls, sufficiant safs spacing and/or shielding shsll be provided to prevent explosion propagation from a donor bay to sdjscent receiver bays.

Various methods are availabls to eccomplish the interruption of e direct line of sight through openings in dividinga wells; three methods of which are described hera.

In the first method or the Maze Concept, items pass through a tunnel arrangement which contains a safe zone. By controlling the flow of items through the safe zone, those items situated on one side of a wall will always be shielded from items on the opposite side. This method will usually require relatively high conveyor speeds to achieve the safe item flow. All elements of the maze must be designed to provide the same protection as the dividing wall.

Method No. 2 utilizes the turntable concept which is an extension of a method used in part for transferring items from one hazardous area to another. In this method, the explosive items pass through a revolving mechanism which is divided into compartments. In it a shield separates adjoining items as they pass through the wall opening. Turntables can be located at the ends of walls and/or within walls. In all cases the speed of the turntable has to be synchronized with the speed of the conveyor. In general, turntables have to revolve at few revolutions per minute in order to maintain conveyor speeds up to 60 feet per minute. Turntables may be constructed of structural steel, aluminum or other structural material. The partitions of the turntables which serve as shields must be capable of preventing propagations between adjoining items. In most cases, tests will be required to establish safe thicknesses of turntables partitions. The turntable must be capable of resisting the blast and fragment effects of a mass detonation at response levels equal to or higher than that of the wall.

The third method is the Blast Lock concept which utilizes a double door arrangement to prevent a direct line of sight. Here, one of the two doors is closed at all times. This method is, in general only, applicable when items flow at very low speeds. As in the other methods, the components of the blast lock must be capable of resisting the blast and fragment effects of an explosion.

TRANSFER OF ITEMS AROUND WALLS, FIGURE 13.

As in the case of items passing through openings in walls, the interruption of the line of sight between operating bays for items moving around walls can be achieved with the use of safe spacing and/or shielding. Figure 13 illustrates this concept. Here, the large number of items of the Hazard Category I operation at the center of Bay 1 are protected from the item traversing the end of the dividing wall by the large safe spacing indicated by Note 1 while the Hazard Category II operation items of Bay 2 are protected by the smaller safe spacing (or shielding) between individual items as indicated by Note 2. Both these separations (and/or shields) would have to be established by testing.

TRANSFER OF EXPLOSIVE BETWEEN BUILDINGS, FIGURE 14.

Depending upon the in-process LAP production stage, transfer of explosive between buildings can be accomplished with the use of pneumatic, hydraulic and/or mechanical conveyance systems. The following discussion covers the mechanical systems where items are moved on mechanical conveyors from one building to another containing production stages beyond the melting process. Three possible conveyance arrangements have been developed which provide the necessary safety to prevent propagation of explosion.

In Arrangement No. 1, individual items and/or lots of items are allowed to accumulate in the ramp between the buildings. In the event of a detonation in the ramp, propagation of explosion will extend throughout the length of the ramp. However, to prevent extension of the explosion into the buildings, effective dividing walls are located at the points where the ramps enter the building. Each of these walls is designed to withstand the effects of a mass detonation in the ramp or within the building it is protecting. Other than the two buildings connected by the ramp, all adjoining buildings must be separated from the ramp based upon the larger of the quantities of explosive in the ramp or in each adjoining building.

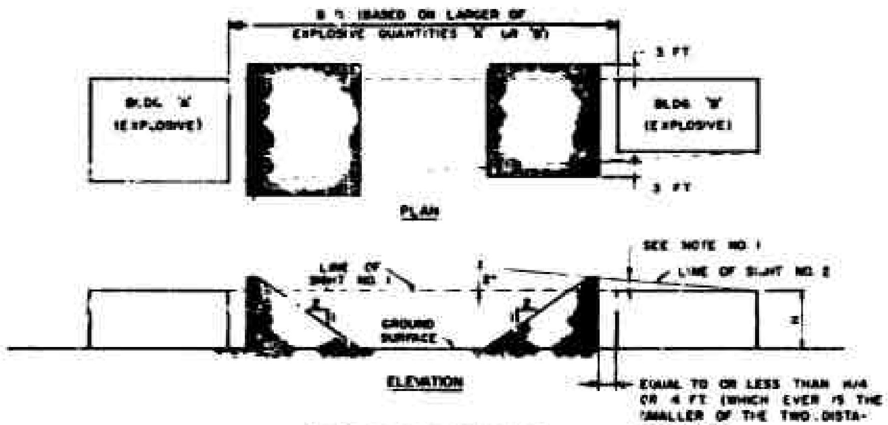
This conveying arrangement is primarily applicable for a conveyor having a straight run between buildings. The introduction of turns will, in turn, reduce the effectiveness of this arrangement and in some cases completely eliminate its effectiveness altogether.

In Arrangement No. 2, Figure 15, all of the individual items or lots of items are separated from one another by safe spacing and/or shielding, thereby preventing the occurrence of a mass detonation within the ramp. The limiting of the explosion propagation will negate the need for dividing walls at each end of the ramp. However, in determining the safe separation requirements, consideration must be given to the safe spacing required to prevent propagation <u>to the ramp</u> produced by a mass detonation within either of the buildings.

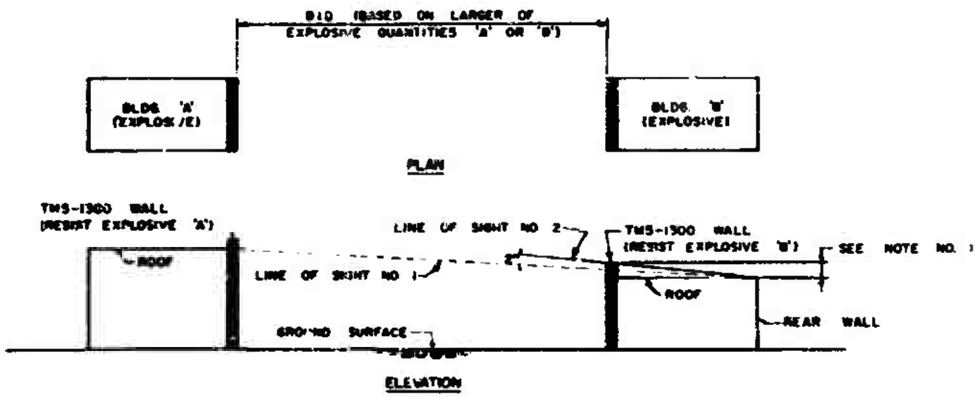
Arrangement No. 3, Figure 16 is a combination of Arrangement Nos. 1 and 2. Here, the individual items (or lots of items) in the ramp are separated by required safe spacing and/or shielding. The effective dividing walls positioned at the ends of the ramp protect the buildings from a detonation in the ramp as well as the explosives in the ramp from an explosion in the building. The use of this system will eliminate the need for establishing a safe separation for the item in the ramp due to a mass explosion in one of the buildings.

CONCLUSION

Although the concepts are not, at the present, of a regulatory nature, their application will facilitate safety reviews and approvals, and in some cases, are to be considered by cognizant safety personnel as modifications and/or supplements to the safety requirements of AMR 385-100



SINGLE REVETTED BARRICADE



DIVIDING WALL BARRICADE

EFFECTIVE BARRICADING - TYPE No. I
(EXPLOSIVE 'A' = EXPLOSIVE 'B')

FIG I

NOTES

1. EQUAL TO SEPARATION DISTANCE BETWEEN BARRICADE AND BUILDING BUT NOT LESS THAN 5 FEET OR AS DEFINED BY LINE OF SIGHT NO. 2
2. FOR TWO BUILDINGS OF DIFFERENT HEIGHTS, SEE NOTE 2 OF PLATE NO. 18
3. EQUAL TO AT LEAST 3 FEET OR AS DEFINED BY LINE OF SIGHT NO. 2.

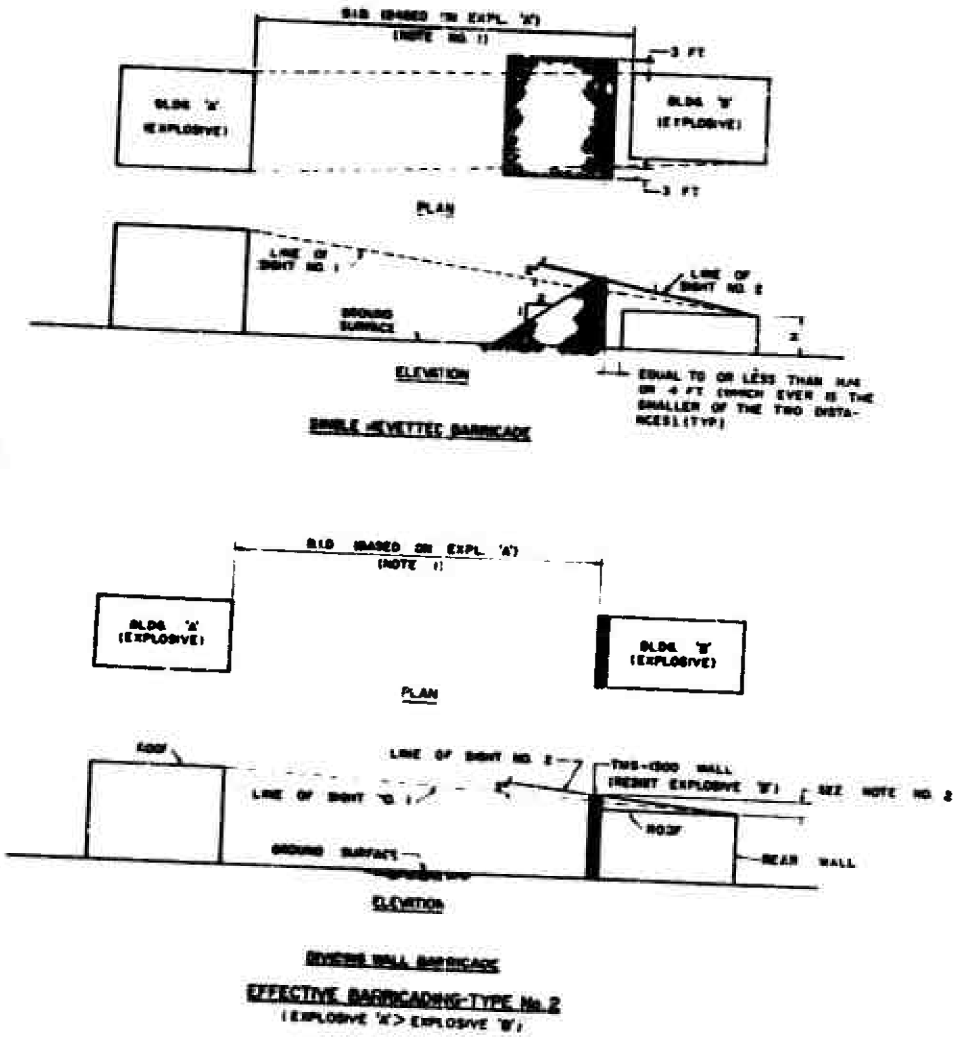
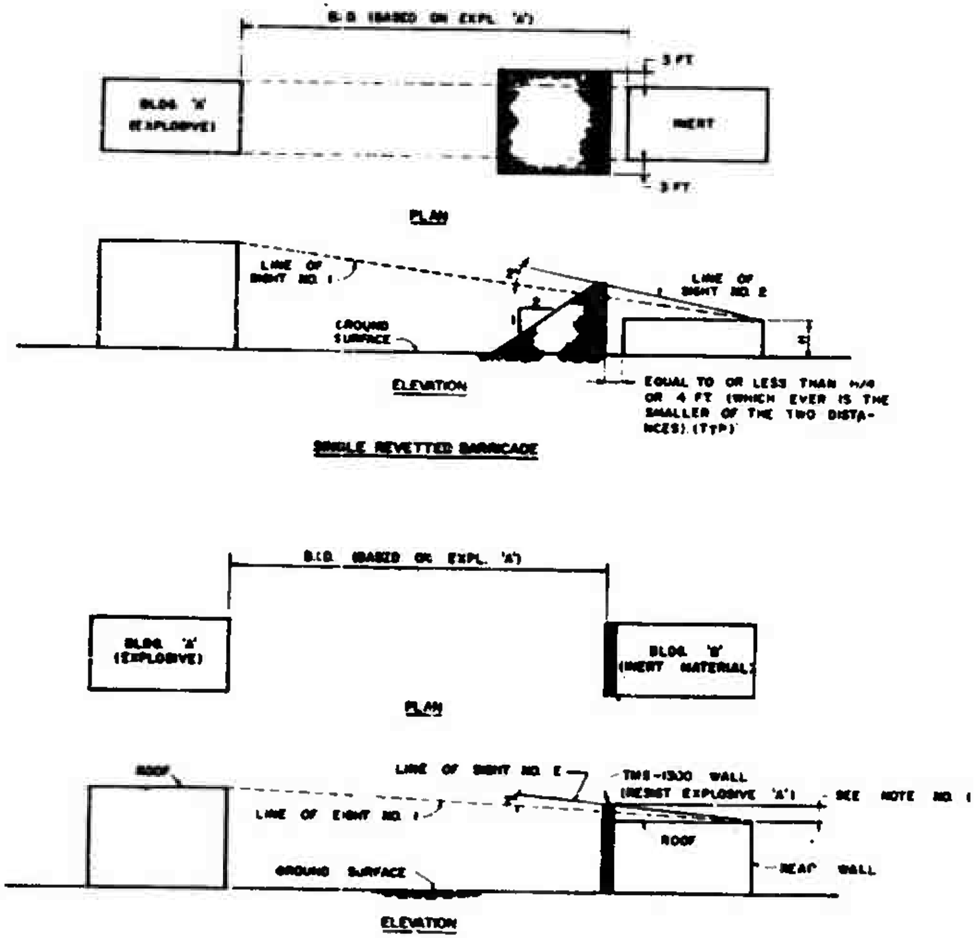


FIG 2

NOTES:

1. FOR THIS SCHEME TO BE APPLICABLE, B.I.D (BASED ON EXPL. 'A') MUST BE EQUAL TO OR GREATER THAN B.I.D (BASED ON EXPL. 'B').
2. BARRICADE HEIGHT TO BE EQUAL TO THE LARGER OF THE BUILDING HEIGHT PLUS THE SEPARATION DISTANCE BETWEEN BUILDING AND BARRICADE, OR 3 FEET ABOVE THE POINT WHERE THE LINE OF SIGHT BETWEEN THE TOPS OF THE BUILDINGS PASS THRU THE BARRICADE OR AS DEFINED BY THE LINE OF SIGHT NO. 2.
3. EQUAL TO AT LEAST 3 FEET OR AS DEFINED BY LINE OF SIGHT NO. 2



SINGLE REVETTED BARRICADE

DIVIDING WALL BARRICADE

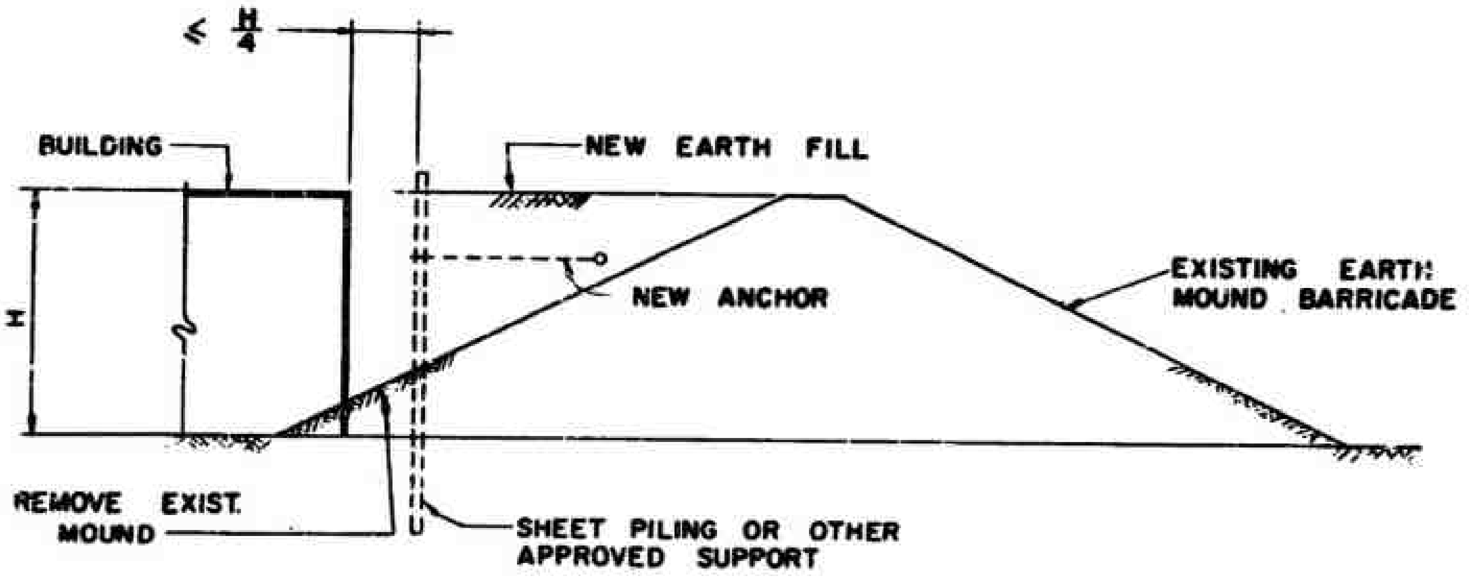
EFFECTIVE BARRICADING TYPE No. 3

NOTES:

1. BARRICADE HEIGHT TO BE EQUAL TO THE LARGER OF THE BUILDING HEIGHT PLUS THE SEPARATION DISTANCE BETWEEN BUILDING AND BARRICADE, OR 2 FEET ABOVE THE POINT WHERE THE LINE OF SIGHT BETWEEN THE TOP OF EACH BUILDING PASS THRU THE BARRICADE OR AS DEFINED BY THE LINE OF SIGHT NO. 2

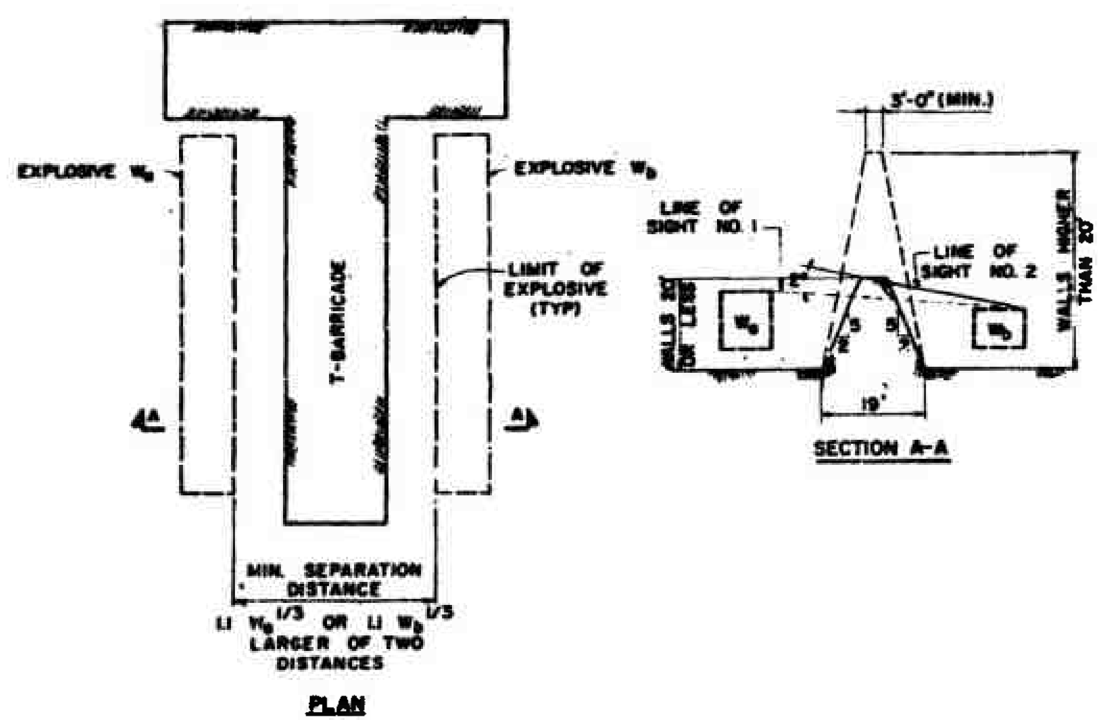
2. EQUAL TO AT LEAST 3 FEET OR AS DEFINED BY LINE OF SIGHT NO. 2

FIG 3



EARTH MOUND BARRICADE
(NOT AN EFFECTIVE BARRICADE)

FIG 4



NOTES

1. HEIGHT OF BARRICADE TO EXTEND 6 FEET ABOVE THE TALLEST EXPLOSIVE CHARGE OR AS OFFINED BY LINE OF SIGHT NO. 2 BUT NOT LESS THAN THE BUILDING HEIGHT.
2. MAXIMUM EXPLOSIVE QUANTITY (W_a OR W_b) NOT TO EXCEED 50,000 POUNDS.

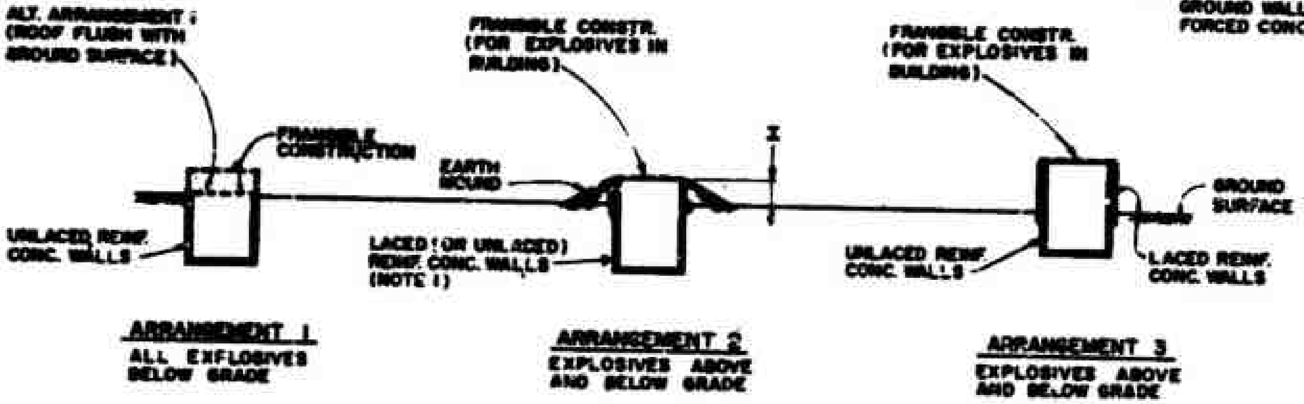
T - BARRICADE

FIG 5

NOTES:

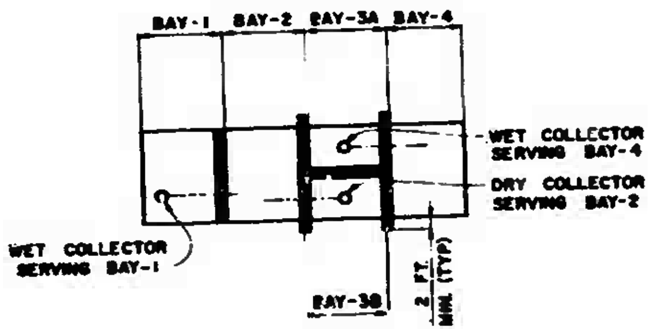
1. WALL HEIGHT (H) EQUAL TO OR LESS THAN 10 FEET. UNLACED REINFORCED CONCRETE MAY BE USED.

2. EXCEPT AS NOTED ABOVE, ALL ABOVE-GROUND WALLS SHALL BE LACED REIN-FORCED CONCRETE.



TYPES OF BELOW-GRADE
EFFECTIVELY BARRICADED BUILDING

FIG 6

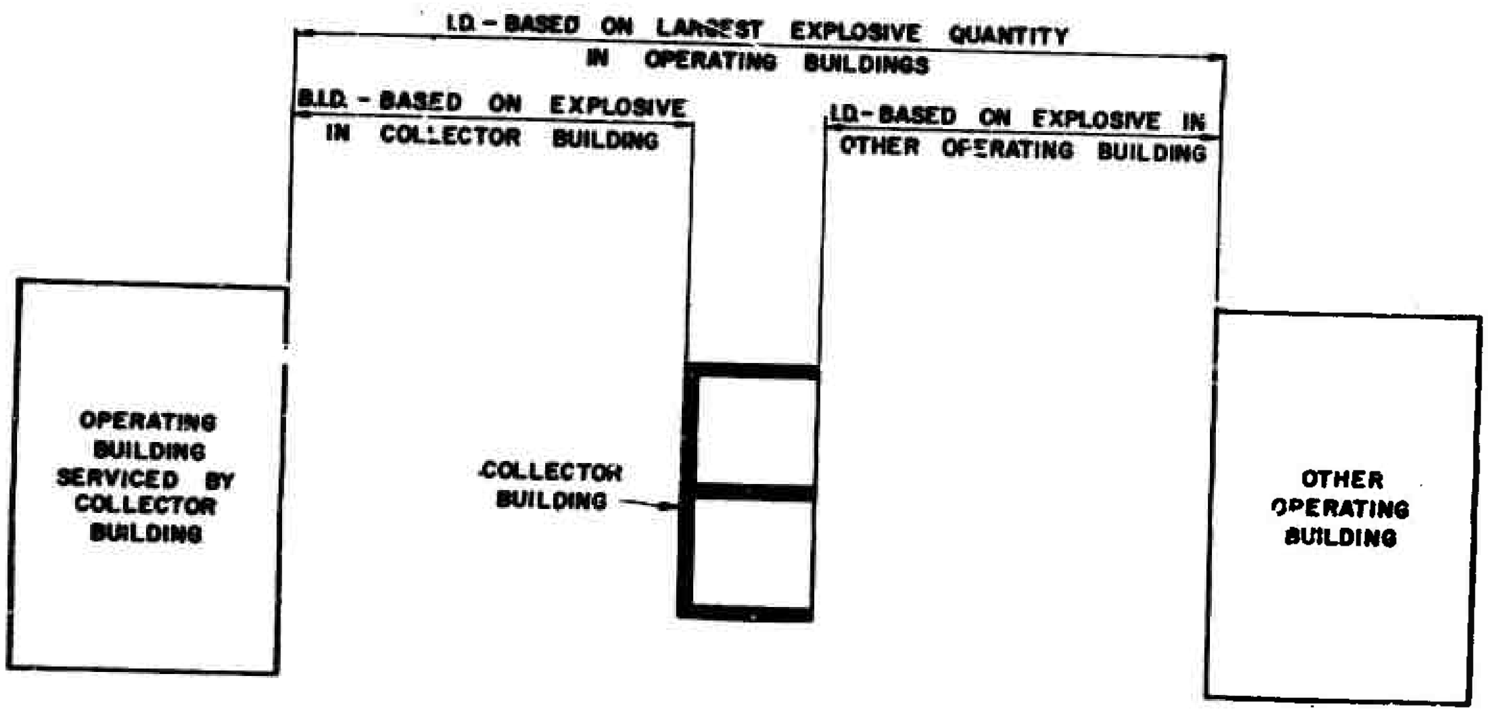


NOTES:

1. WET COLLECTOR MAY BE LOCATED IN THE OPERATING BAY IT IS SERVING OR IN A SEPARATE BAY
2. EACH DRY COLLECTOR SHALL BE LOCATED IN A SEPARATE ENCLOSED BY THREE WALLS.
3. COLLECTOR BAYS SHALL NOT BE USED FOR OTHER OPERATIONS OR AS A COMMUNICATING CORRIDOR OR PASSAGE WAYS.
4. MAXIMUM EXPLOSIVE QUANTITY ACCUMULATED IN ANYONE COLLECTOR WITHIN AN OPERATION BUILDING SHALL NOT EXCEED 5 POUNDS.

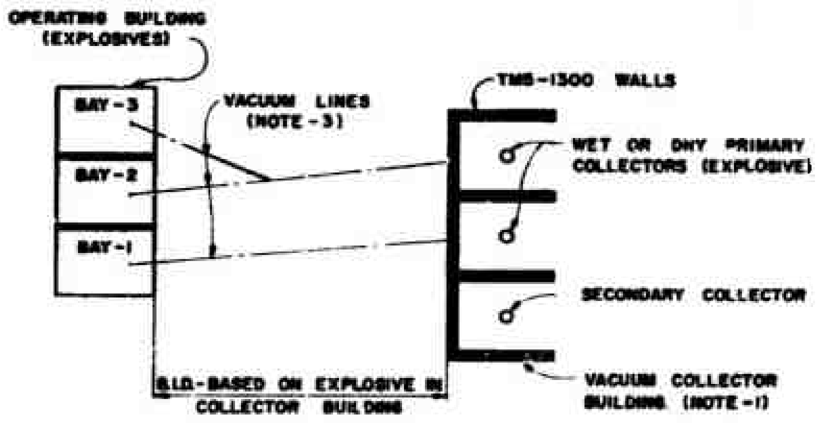
EXPLOSIVE DUST COLLECTORS
(IR OPERATING BUILDINGS)

FIG 7



Q.D. SEPARATION BETWEEN
COLLECTOR & OPERATING BLDG'S

FIG 8



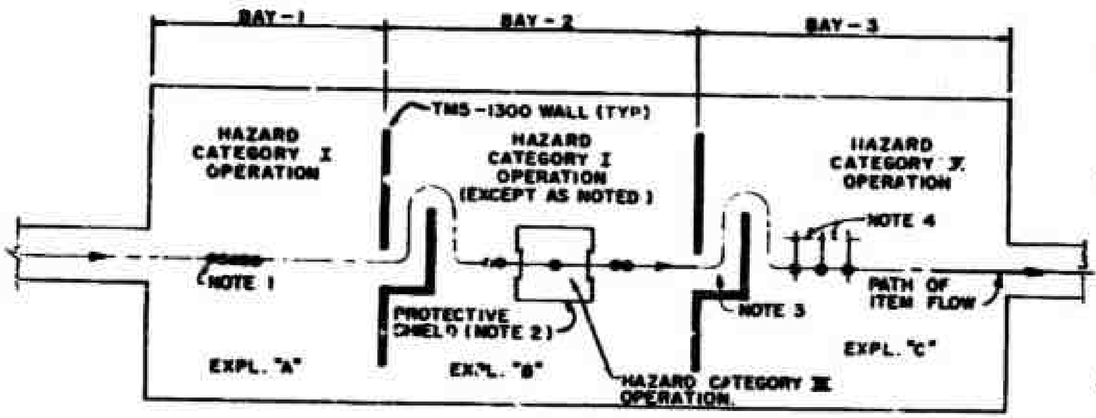
PLAN

EXPLOSIVE COLLECTORS
(EXTERIOR OF OPERATING BLDG'S)

NOTES:

1. A VACUUM COLLECTOR BUILDING SHALL SERVE NO MORE THAN ONE OPERATING BUILDING. A PRIMARY VACUUM COLLECTOR SHALL SERVE ONLY ONE OPERATING AREA WITHIN THE OPERATING BUILDING AND SHALL BE LOCATED IN A SEPARATE BAY IN THE VACUUM BUILDING. A SECONDARY VACUUM COLLECTOR SHALL ALSO BE LOCATED IN A SEPARATE BAY AND SHALL SERVICE NO MORE THAN TWO PRIMARY COLLECTORS.
2. A CENTRALLY LOCATED POLLUTION ABATEMENT PROCESSING FACILITY MAY BE USED TO SERVE MORE THAN ONE VACUUM COLLECTOR BUILDING AND SHALL BE LOCATED AT MINIMUM INTRALINE DISTANCES FROM ALL OTHER OPERATING FACILITIES
3. VACUUM AND/OR EXPLOSIVE WASTE LINES SHALL BE PROVIDED WITH DETONATION TRAPS OR OTHER POSITIVE MEANS TO PREVENT A PROPAGATION OF EXPLOSION BETWEEN VACUUM COLLECTORS AND OPERATING AREAS AND OTHER EXPLOSIVE COLLECTION FACILITIES.
4. ACCUMULATION OF MORE THAN 5 POUNDS OF EXPLOSIVES SHALL BE ACCOMPLISHED IN A COLLECTOR BUILDING SEPARATED FROM THE OPERATING BUILDING IT IS SERVICING.

FIG 9



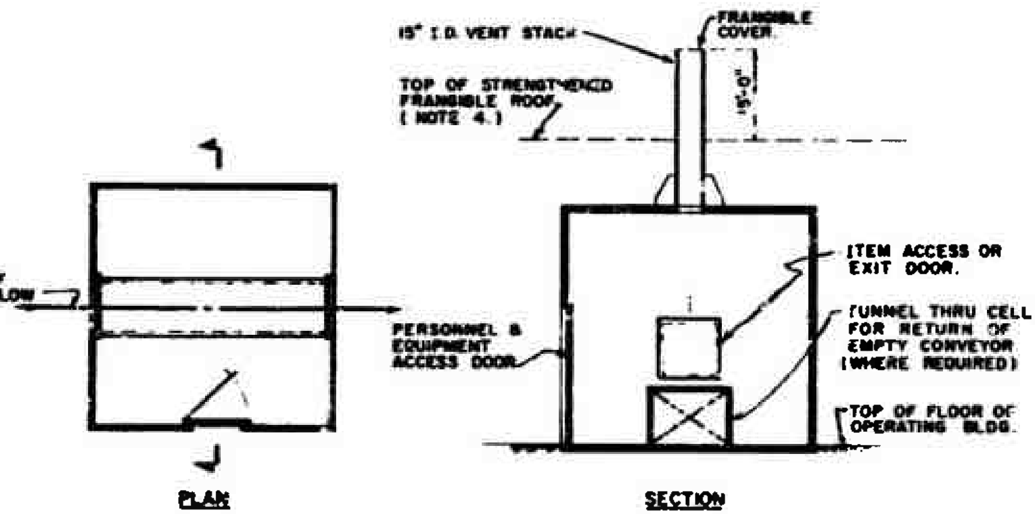
PLAN

NOTES:

1. NO ITEM SEPARATION REQUIRED FOR HAZARD CATEGORY I OPERATIONS.
2. PROTECTIVE SHIELD SHALL BE DESIGNED FOR THE EXPLOSIVE QUANTITY CONTAINED THEREIN TO PROTECT PERSONNEL AND EQUIPMENT OUTSIDE THE SHIELD FOR HAZARD CATEGORY II OPERATIONS.
3. MAZES OR OTHER EFFECTIVE MEANS SHALL BE PROVIDED TO (1) PREVENT A DIRECT LINE OF SIGHT BETWEEN ITEMS IN ADJOINING BAYS, AND (2) REDUCE THE SEPARATION DISTANCES REQUIRED, BETWEEN THE AND THE ADJOINING BUILDINGS, BASED UPON THE TOTAL QUANTITY OF EXPLOSIVE IN THIS BUILDING; TO THOSE SEPARATIONS BASED UPON THE QUANTITY OF EXPLOSIVE IN INDIVIDUAL BAYS.
4. SAFE SPACING OR SHIELDING BETWEEN ITEMS REQUIRED FOR HAZARD CATEGORY II OPERATIONS (TO BE ESTABLISHED BY TESTING).

HAZARD CATEGORY DESCRIPTION

FIG 10

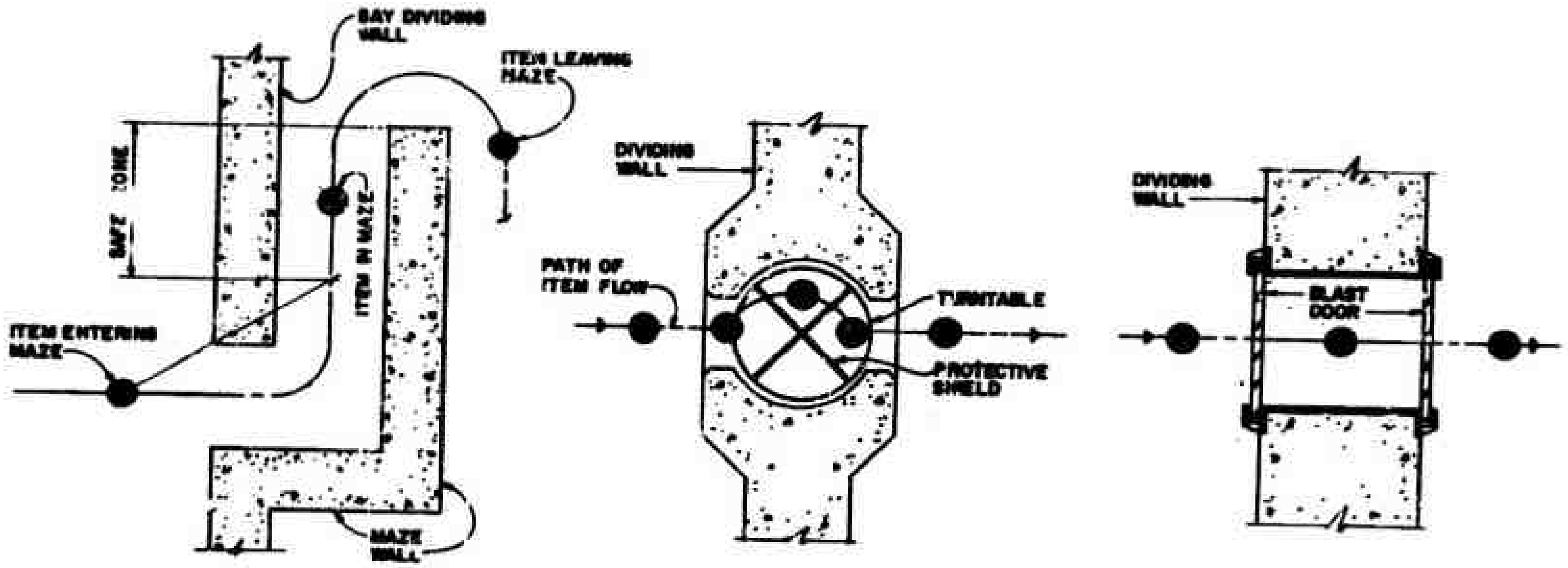


NOTES:

1. MAX QUANTITY OF EXPLOSIVE WITHIN THE SHIELD SHALL NOT EXCEED 15 POUNDS. LARGER QUANTITIES OF EXPLOSIVE SHALL BE LOCATED IN SEPARATE OPERATING BUILDINGS.
2. SHELL, DOORS & VENT STACK SHALL BE CAPABLE OF RESISTING THE BLAST AND FRAGMENT (PRIMARY & SECONDARY) EFFECTS OF AN EXPLOSION WITHIN THE SHIELD.
3. ALL DOORS SHALL BE CLOSED DURING PERFORMANCE OF HAZARDOUS OPERATIONS.
4. FRANGIBLE PORTION OF THE OPERATING BLDG. SURROUNDING THE SHIELD SHALL HAVE SUFFICIENT STRENGTH TO RESIST A BLAST PRESSURE OF 1.5 p.s.i.
5. ALL HAZARD CATEGORY III OPERATIONS SHALL BE PERFORMED REMOTELY.

HAZARD CATEGORY III OPERATIONAL SHIELD

FIG 11



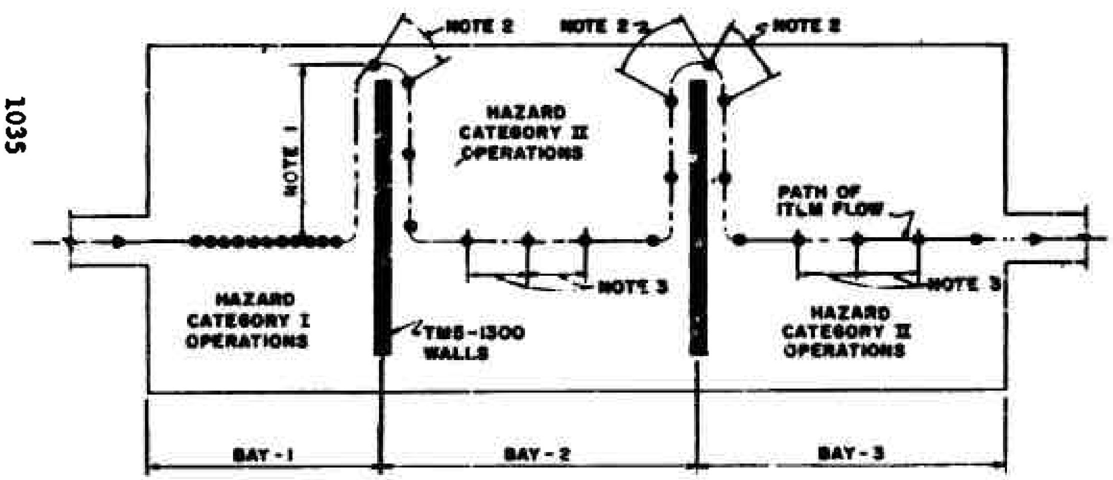
MAZE CONCEPT

TURNTABLE CONCEPT

BLAST LOCK CONCEPT

METHODS USED TO PROTECT
PASS-THRU OF DIVIDING WALL

FIG 12

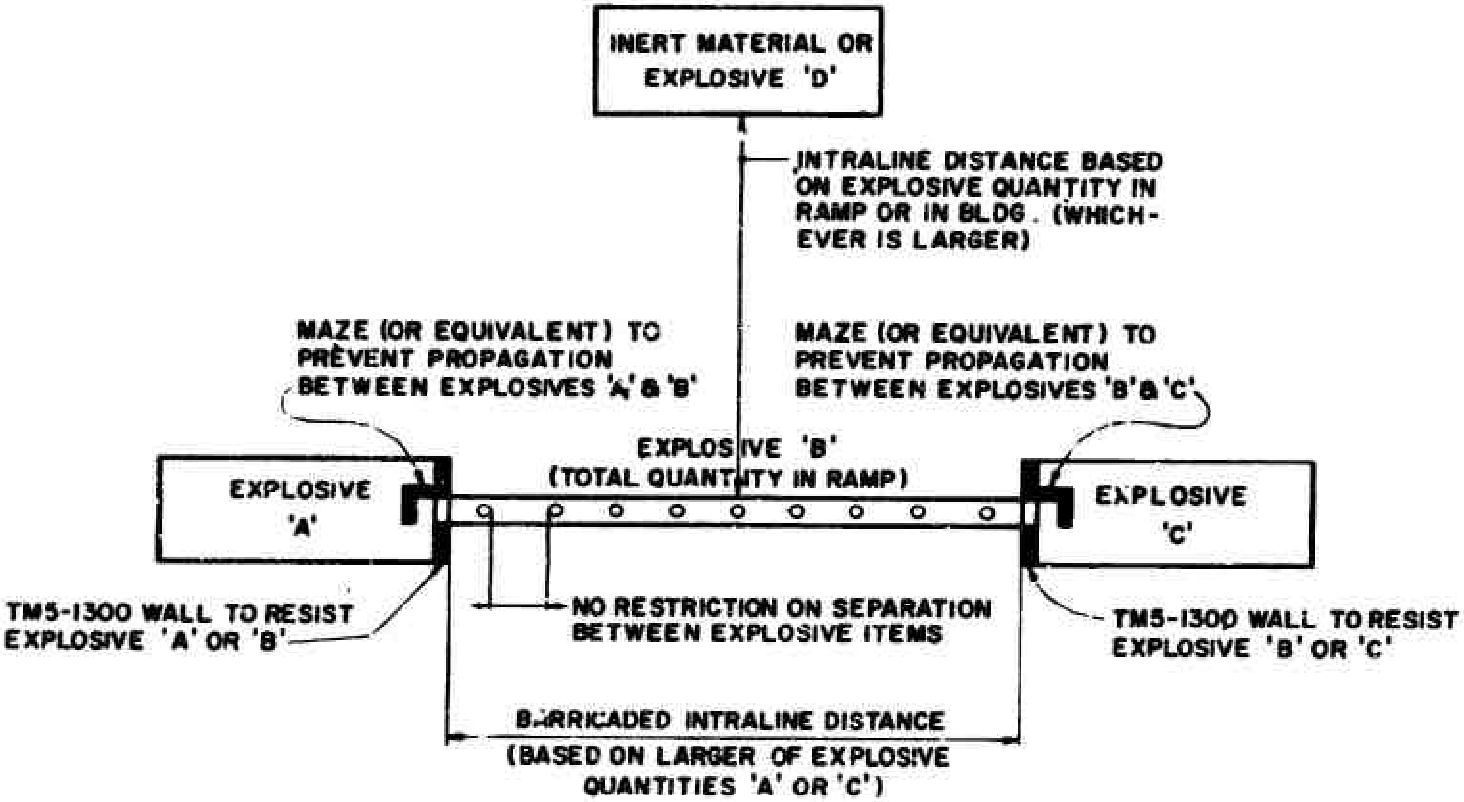


NOTES:

1. SAFE SPACING AND/OR SHIELDING REQUIRED TO PREVENT PROPAGATION OF EXPLOSION TO BAY-1 DUE TO A MASS DETONATION IN BAY-2.
2. SAFE SPACING AND/OR SHIELDING REQUIRED TO PREVENT PROPAGATION OF EXPLOSION TO BAY-2 FROM A MASS DETONATION IN BAY-1 OR BAY-3 OR TO BAY-3 FROM A MASS DETONATION IN BAY-2.
3. SAFE SPACING AND/OR SHIELDING REQUIRED BETWEEN ITEMS FOR CATEGORY II OPERATIONS.

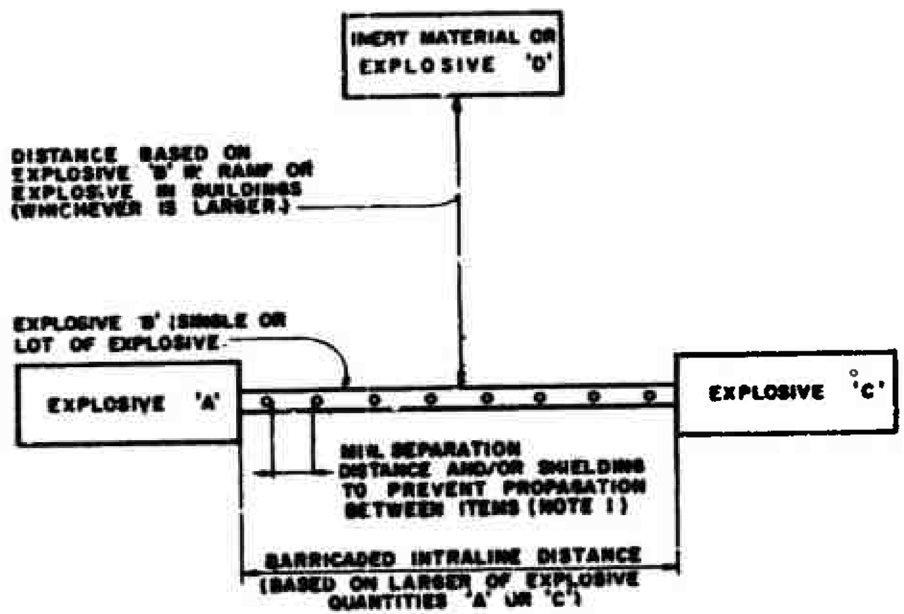
REQUIREMENTS FOR TRANSFER OF EXPLOSIVES AROUND OR OVER DIVIDING WALLS

FIG 13



TRANSFER ARRANGEMENT NO. 1

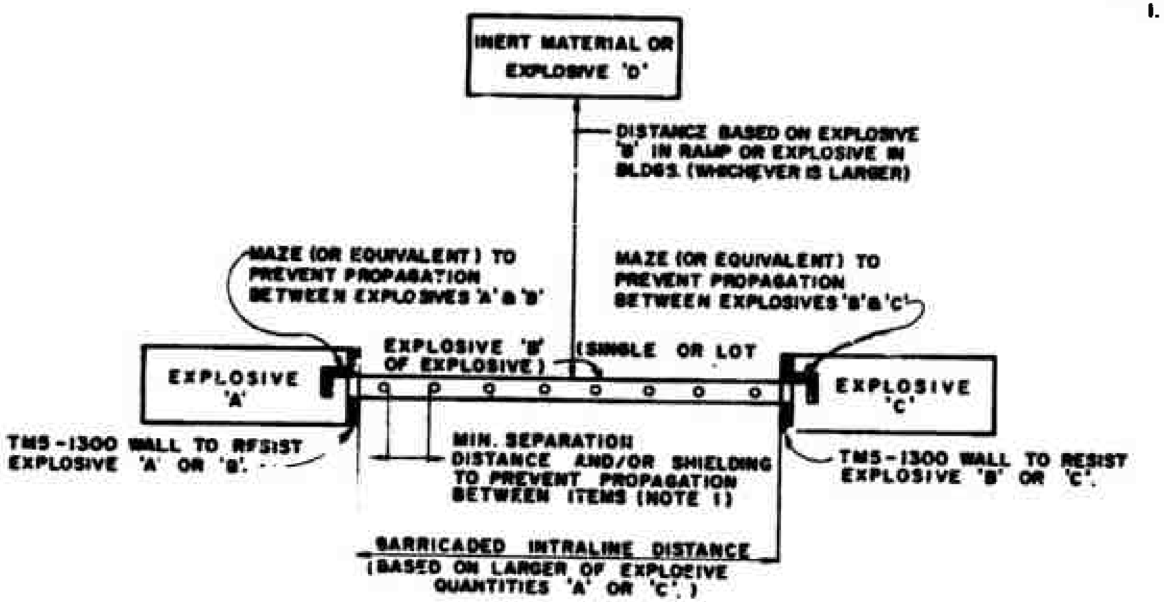
FIG 14



TRANSFER ARRANGEMENT No. 2

NOTES:
1. MINIMUM SEPARATION DISTANCE AND/OR SHIELDING TO PREVENT PROPAGATION SHALL BE ESTABLISHED BY TESTING.

FIG 15



NOTES:

1. MINIMUM SEPARATION DISTANCE AND/OR SHIELDING TO PREVENT PROPAGATION SHALL BE ESTABLISHED BY TESTING.

TRANSFER ARRANGEMENT No. 3

FIG 16

ANALYSIS OF FIVE YEARS OF AIR QUALITY DATA TAKEN IN THE VICINITY OF A TNT MANUFACTURING PLANT

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Edgewood Arsenal, Md.

ABSTRACT

Volunteer Army Ammunition Plant, Chattanooga, Tennessee, was reactivated during 1966 for the production of TNT. Using existing facilities which were built in 1941, the plant was at full production (10 TNT lines operating) by March 1967. The reactivation was accomplished under government contract by Atlas Chemical Industries, Inc. Realizing the extent of environmental pollution (both air and water) which resulted from the batch-type process, considerable effort and expenditures were made to control the emissions. Most control efforts were directed toward the emissions of sulfur dioxide, particulates and acid mist. Suitable control equipment for nitrogen oxides, was not available. Surveillance included a four station ambient air quality network which was established to monitor the air pollutants and contribute to process control. Sampling was performed on a continuous basis for nitrogen dioxide (NO_2), nitrogen oxide (NO), sulfur dioxide (SO_2), suspended particulates and, beginning in July 1969, acid mist (as H_2SO_4). A review of the air quality data for the period 1 January 1967 - 31 December 1971 was completed. This paper provides a comparison of air quality data with applicable standards. Further, evaluation of abatement measures is discussed using trend analysis. Analysis of the data indicates the following:

a. Ambient levels monitored indicate exceptional control of the emissions of SO_2 and acid mist.

b. Pollution abatement for particulates appears to have had marginal effect on ambient levels.

c. Although the ambient levels of nitrogen dioxide monitored at the stations have been excessive, compliance with current standards is indicated when the plant 's operating two TNT lines or less.

ANALYSIS OF FIVE YEARS OF AIR QUALITY DATA
TAKEN IN THE VICINITY OF A TNT MANUFACTURING PLANT*

1. BACKGROUND.

a. Plant Operation. Volunteer Ordnance Works were built in late 1941 and consisted of 16 TNT lines, three acid areas, storage and administrative areas. Located in an isolated area northeast of Chattanooga, little consideration was given to pollution control. Since that time, the plant was reactivated on several occasions in response to the country's need for explosives. During the Korean conflict, ten TNT lines were rehabilitated as well as the North and East Acid Areas and all supporting and administrative facilities. However, no more than six TNT lines were placed in operation. The operating contractors, Atlas Powder Company, conducted various studies to determine methods of controlling pollution from the process; however; the operation was terminated before many of the controls could be implemented. A major modification was made on the acid and fume recovery system where added oxidation space resulted in the recovery of an estimated 8,000 pounds of nitric acid that had formerly been vented to the atmosphere. Cyclone filters were installed on three of the four boilers at the No. 1 power house and Mahon Fog Filters were installed on two sulfuric acid concentrators (SAC) in the North Acid Area. Figure 1 depicts the plant in its current configuration.

Following the Korean conflict, significant changes in population trends resulted in the construction of housing developments around the plant, particularly to the north of the plant. The area was also developed for recreation purposes. Again, the major development occurred to the north of the plant along Waconda Bay. Figure 2 is an area map showing the plant and the Chattanooga Metropolitan Area.

In November 1961, Farmers Chemical Association, Incorporated leased a significant portion of the plant, including the North Acid Area, for the production of nitric acid and ammonium nitrate fertilizer. The Association also assumed protective surveillance of the entire plant which continued

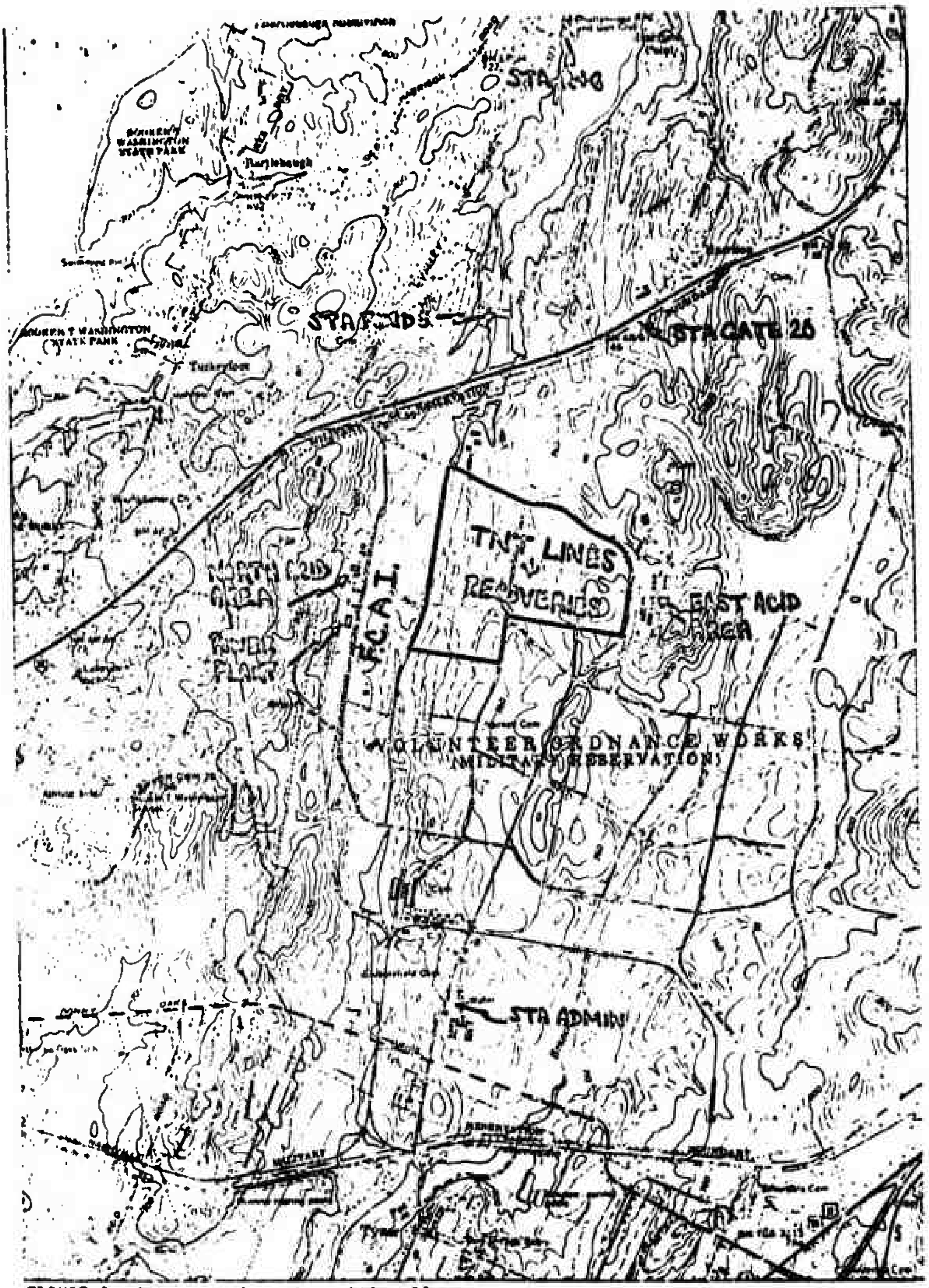
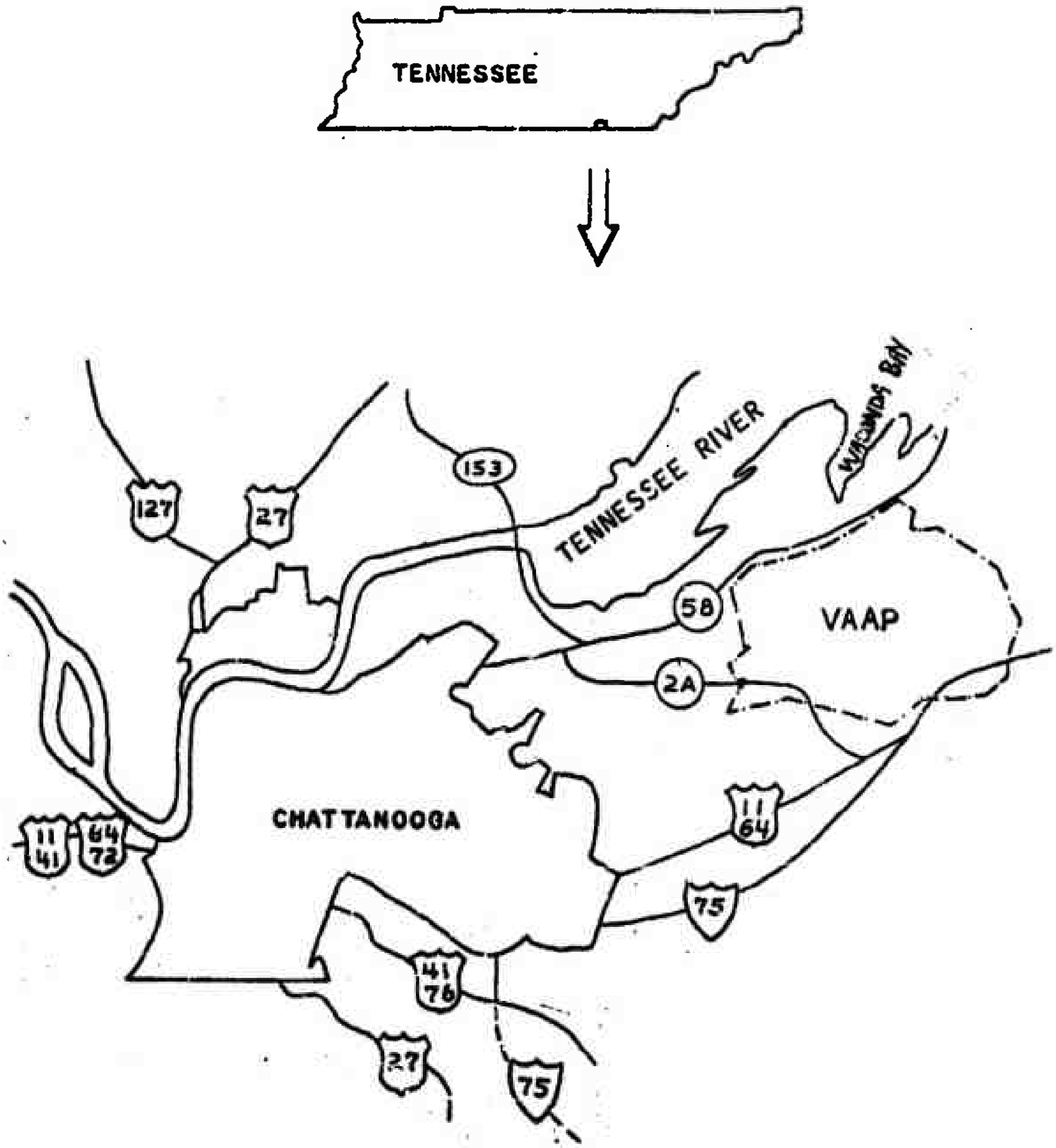


FIGURE 1 Volunteer Army Ammunition Plant



TGURE 2 Area Map

until reactivation on 1 October 1965. On this date the plant was reopened for the Viet Nam conflict under contract with Atlas Chemical Industries, Incorporated.. formerly Atlas Powder Company. The Plant was renamed Volunteer Army Amminition Plant (VAAP). Due to the urgent requirements for TNT, the present reactivation was performed very rapidly. Production was resumed on 5 March 1966 and increased to ten TNT lines operating by March 1967. Concurrent with the ammonium nitrate production and the reactivation of the TNT process, a series of complaints, petitions, and damage suits were made against the plants operation. An organization was formed to present the objections of the local residents to the environmental pollution caused by the plant. Several meetings, which included representatives of the citizens, the plant, the US Army and local and Federal government agencies were held to determine necessary action. The US Army Environmental Hygiene Agency (USAEHA) participated in the planning for pollution abatement. Stack sampling and ambient air sampling surveys were conducted by USAEHA during 1966 and 1967 to assess the impact of the atmospheric emissions. As a result of these meetings and surveys an extensive pollution abatement program was initiated.

b. Topography and Climatology. VAAP, located in southeastern Tennessee in Hamilton County, is situated approximately 12 miles northeast of downtown Chattanooga. Bordering Chattanooga on the west and south sides are Signal Mountain and Lookout Mountain. Both these ranges are slightly over 2,000 feet above sea level (MSL). To the east is Missionary Ridge with an elevation slightly over 1,000 feet MSL which separates the city of Chattanooga and VAAP. Further, to the east are the Whiteoak Mountain Ridges, with an elevation slightly over 1,300 feet MSL. These ridgelines oriented north-northeast and south-southwest enclose the area within an air shed. Hills bordering the plant on the east and west effectively create a valley within a larger valley. These hills run essentially north-northeast and south-southwest and range from 920 feet MSL on the west to 1,000 feet MSL on the east. As a result of the topography of the plant area, prevailing winds are from the south and south-southwest.

A review of the weather records for Lovell Field, located south of the plant, indicated that winds from the south and south-southwest occur 21% of the time annually. Calms or periods of atmospheric stagnation occur frequently in this area. Chattanooga is located at one of the two centers in the country noted for high frequency of prolonged (4 days or more) atmospheric stagnations.[1] In addition to the adverse affects of

[1] Korshover, J., Climatology of Stagnating Anticyclones East of the Rocky Mountains, 1936-1965, US Public Health Service Publication No. 999-AP-34, US Department of Health, Education, and Welfare, Cincinnati, Ohio, 1967.

channeling and atmospheric stagnation, night time inversions are frequent in the Chattanooga area. Table 1 lists the occurrence of inversion conditions as reported by C. R. Hosler.[2] As a result, the wind frequently carries pollutants towards Waconda Bay, and the homes and recreation area north of the plant without adequate dispersion.

TABLE 1

INVERSION FREQUENCIES

Season	Percent Nighttime	Percent Total Time
Winter	60	41
Spring	70	32
Summer	78	44
Fall	78	45
Annual	72	40

c. Air Sampling Station Configuration. Following the completion of the ambient air survey conducted by this Agency at VAAP it was determined that a four station air monitoring network would be established. In the fall of 1966, two continuous sampling stations were installed, one located at the Chattanooga Rod and Gun Club adjacent to Waconda Bay, the other located across from the Harrison Elementary School at Gate 20 of the plant (See Figure 1). Continuous monitors were installed at two other sampling points, Pond 5 and the Administration Area in April 1967. Respectively, the stations are identified as R&G, Gate 20, Pond 5, and Admin. Sampling for suspended particulate matter has been conducted throughout the period using Hi-Volume samplers. Manual sampling for acid mist (described as H_2SO_4) has been conducted at the four stations; however, a satisfactory sampling method was not developed until July 1969. The four sampling stations were equipped to continuously monitor the following gaseous pollutants, nitrogen oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). In February 1968, a calibration check of the continuous analyzers was made by US Public Health Service personnel. As a result, the data resolved at stations Admin and Pond 5 were declared invalid. In February and May 1968, replacement analyzers were installed in Stations Admin and Pond 5 identical to the equipment in the other two stations. Pollutant analysis is described below:

[2] Hosler, C. R., Low Level Inversion Frequency in the Contiguous United States. Monthly Weather Review. 89: 319-339, September 1961.

(1) NO_2 - The continuous analysis of NO_2 is based upon the Technicon procedure of Yunghaus and Monroe. The NO_2 is absorbed in a modified Saltzman reagent with subsequent color development in proportion to the NO_2 concentration.

(2) NO - The sample air containing NO and NO_2 is passed through a liquid potassium permanganate scrubber to oxidize the NO to NO_2. Concentration are determined as in (1) above. The concentration of NO is equal to the difference in the two NO_2 concentrations.

(3) SO_2 - The SO_2 is continuously monitored on an Autoanalyzer. This system uses a modified West and Gaeke solution for absorption of the SO_2 with subsequent color development in proportion to the ambient SO_2 concentration.

(4) H_2SO_4 Acid Mist - The acid mist is collected on a Millipore filter for a period of 24 hours at a sampling rate of 10 l/min. Total acidity is determined by titration to an end point.

(5) Particulates - The suspended particulates are collected by Hi-volume samplers for a period of 24 hours. Glass fiber filters are weighed before and after sampling for a weight analysis.

(6) Data reduction - For the various pollutants, a conservative approach was taken in reducing the data to average values.

(a) For NO and NO_2, all values between zero and 0.01 ppm are reported as 0.01 ppm.

(b) For SO_2, all values between zero and 0.005 ppm are reported as 0.005 ppm.

(c) For H_2SO_4, all values between zero and 0.005 mg/M^3 are reported as 0.005 mg/M^3.

(d) As an aid in process control, the monitoring network also includes a wind instrument which is located near Station Pond 5.

d. Current Air Quality Standards. The following air quality standards are applicable to the pollutants presently monitored at the four station network.

(1) Sulfur Oxides (reported as SO_2) - Annual arithmetic mean of 0.02 ppm, 24-hour maximum value of 0.1 ppm not to be exceeded more than once in

any 12-month period; 3-hour maximum value of 0.5 ppm not to be exceeded more than once per year, and 1-hour maximum of 0.3 ppm.[3,4]

(2) Nitrogen dioxide (NO_2)* - Annual arithmetic mean of 0.05 ppm.[3]

(3) Acid mist (as H_2SO_4) - Average value of 0.015 ppm (0.06 mg/M^3) not to be exceeded.[5]

(4) Particulates - Annual geometric mean of 60 mg/M^3, 24-hour maximum value of 150 mg/M^3 not to be exceeded more than once per year.[3]

2. DISCUSSION.

a. The air quality data was summarized for the period 1 January 1967 through 31 December 1971. During this five year period the plant operated at different levels of production. On 1 January 1967, full scale production was approached with the start-up of the 9th TNT line. The plant was in full production operating 10 TNT lines by 23 March 1967. Production at this rate continued until 31 January 1969 after which 9 lines were operated through 22 October 1969. Subsequent reductions occurred as follows:

(1) Eight lines on 23 October 1969.

(2) Seven lines on 29 December 1969.

(3) Six lines on 2 February 1970.

(4) Five lines on 15 May 1970.

(5) Three lines on 1 February 1971.

(6) Two lines on 13 December 1971.

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[3] Federal Register, (Reprint), US Public Health Service, 36(21): 1502-1515, US Department of Health, Education, and Welfare, January 30, 1971.

[4] Chattanooga - Hamilton County Air Pollution Control Ordinance Section 9, Rules 13.1 and 13.2.

* Nitrogen Oxide (NO) is not found in the ambient air in concentrations high enough to be considered an air pollutant.

[5] Letter, USAEHA-EA, US Army Environmental Hygiene Agency, 16 June 1969, subject: Air Pollution Potential from the Incineration of Mustard, and indorsement thereto.

Three time periods were selected for examination and are related to the level of production. The first period runs from January 1967 through December 1969 during which eight to ten TNT lines were operated. The second period lasting from January 1970 through January 1971 was selected to analyze the data resulting from the operation of five to seven TNT lines. During the balance of 1971, the third period, 3 TNT lines were operated. Some overlap of production level was ignored so that complete months could be considered. For example on 13 December 1971, production was cut to two lines; nonetheless, the month of December was treated as if three lines were in operation. Pollution abatement efforts were carried out throughout the five year period and will be discussed individually as appropriate. Two major pollution abatement efforts were completed in 1966. The red water evaporation and incineration processes were rehabilitated to reduce the air and water emissions. Mahon fog filters were installed at the North and East acid area sulfuric acid concentrators (SAC) to reduce the emission of acid mist.

b. The air quality data were reduced to a monthly arithmetic mean. Two monthly averages were determined for the data sampled during the first period of production (1 January 1967 - 31 December 1969). The gaseous pollutants (SO_2 and NO_2) were analyzed initially as one-hour averages by personnel at VAAP and further averaged to a daily mean. The acid mist and suspended particulate samples represent a 24-hour average. In this format of daily averages the air quality data are reported monthly, with this Agency as one of the recipients. From this subgroup or monthly mean ($\bar{X}$, two monthly mean for the first production period) a grand average for the period ($\bar{\bar{X}}$) was resolved as suggested by E. L. Grant.[6] This method offers a means of comparing averaged data and control limits against the individual readings. To allow for variation within the data the control limits or confidence intervals were specified to three standard deviations about the average range ($\bar{R}$). Subgroups are also used in the method of least squares to resolve trend lines. Grand averages ($\bar{\bar{X}}$) were also determined yearly for comparison with applicable air quality standards.

3. FINDINGS.

a. Nitrogen Dioxide.

(1) Table 2 illustrates the annual arithmetic mean for the five year period of record. The values would certainly indicate that the batch-type process for the production of TNT results in excessive levels of NO_2 in and around the plant. These levels exceed the current federal standard, annual arithmetic mean of 0.05 ppm.

E. L. Grant, Statistical Quality Control, McGraw-Hill Book Company, Incorporated, 1946.

TABLE 2

NITROGEN DIOXIDE (PPM)
CALENDAR YEAR

STATION	1967	1968	1969	1970	1971
Admin	-	0.098	0.113	0.066	0.051
Pond 5	-	0.193	0.180	0.118	0.077
R&G	0.074	0.146	0.130	0.100	0.067
Gate 20	0.135	0.098	0.099	0.061	0.044
Average	-	0.134	0.131	0.085	0.060

(2) Table 3 illustrates the arithmetic mean by period of production level. The first represents 8-10 TNT lines operating, the second period represents 5-7 lines and the third period represents three lines.

TABLE 3

NITROGEN DIOXIDE (PPM)
PRODUCTION PERIOD

STATION	FIRST	SECOND	THIRD
Admin	0.106	0.065	0.051
Pond 5	0.185	0.116	0.077
R&G	0.117	0.100	0.067
Gate 20	0.111	0.061	0.044
Average	0.130	0.086	0.060

(3) There is considerable variability in the data with the largest variability occurring at Pond 5 The standard deviation (S) estimated from the average monthly range are listed in Table 4 by production period. In addition, the three standard deviation (3S) control limits for $\bar{R}$ are listed. These control limits would include 99.73% of all the monthly ranges found within each production period.

TABLE 4

NITROGEN DIOXIDE (PPM)
PRODUCTION PERIOD

STATION	FIRST S	FIRST UCL ; LCL*	SECOND S	SECOND UCL ; LCL	THIRD S	THIRD UCL ; LCL
Admin	0.123	0.680;0.101	0.058	0.194;0.049	0.039	0.248;0.033
Pond 5	0.210	1.188;0.147	0.119	0.671;0.099	0.072	0.399;0.060
R&G	0.129	0.744;0.180	0.192	0.640;0.095	0.089	0.489;0.073
Gate 20	0.120	0.694;0.168	0.105	0.351;0.052	0.035	0.191;0.029

* UCL - Upper Control Limit; LCL - Lower Control Limit.

(4) Considerable effort was expended to reduce NO_x emissions with the measures that were available at the time. The following summarizes the measures in chronological order. Items (a) - (f) describe abatement measures which occurred during the first production period. Item (g) was completed during the second period.

(a) The following processes were instrumented for better control of the operation and to reduce NO_x emissions.

(1) All acid and fume recoveries - July 1967.

(2) Nitric Acid Concentrator (NAC) - December 1967.

(3) All recoveries were modified with additional instrumentation - July 1968.

(4) Ammonia Oxidation Plant (AOP) - December 1968.

(b) Eliminate exhausting AOP fumes by connecting vent to NAC adsorption system - May 1967.

(c) Farmers Chemical Association, Inc. powerhouse converted from coal to gas and oil (this represents a decrease in SO_2 and particulates with an increase in NO_x emissions) - June 1967.

(d) Conversion of five inch fume line Headers to eight inch Headers from Tri-house to recoveries. Eliminates exhaust of NO_2 fumes due to pressure build-up - February 1968.

(e) Red water incinerators converted to natural gas (resulting in a decrease in SO_2 and particulates and an increase in NO_x emissions) - July 1969.

(f) All red water incinerators shut down - September 1969.

(g) Install additional bubble cap towers at four acid and fume recoveries to increase the absorption capacity for NO_x fumes - March 1970.

b. As listed above, considerable work was done in an effort to control NO_x emissions. During the first production period, no direct controls are indicated since none were available. Most abatement measures were directed toward improved instrumentation which contributed to process control. In the second period direct control of the NO_x fumes off the recoveries was attempted with the addition of bubble cap towers. A least square trend analysis was completed by production period in an attempt to assign significance to the control effort. Table 5 lists the slopes for the four air sampling stations by period.

TABLE 5

NITROGEN DIOXIDE
PRODUCTION PERIOD TRENDS

STATION	FIRST	SECOND	THIRD
Admin	0.005	-0.004	-0.0002
Pond 5	0.004	-0.006	-0.003
R&G	0.006	-0.005	-0.002
Gate 20	-0.003	-0.001	-0.002

(1) The least squares trend lines for the four stations are illustrated in Appendix A. As indicated, there is a significant increase during the first period reflected at Stations, Admin, Pond 5, and R&G. At Station Gate 20, the trend was down for the same period. The largest increase in NO_2 levels was found at Station R&G where the average level of 0.069 ppm at the beginning of the period increased to 0.165 ppm at the end of the period. The increase could have resulted from the following.

(a) Conversion of fuel to natural gas at the powerhouse - June 1967.

(b) Start-up of the 500 ton/day nitric acid concentrator (NAC) at the North acid area - Fall 1967.

(c) Conversion of fuel to natural gas at the red water incinerators - July 1969 (Incinerators were shut down in September 1969).

(2) Note that these sources are all located on the western part of the plant and are more likely to affect Stations Admin, Pond 5, and R&G with winds channeled along the north-northeast and south-southwest orientation. However, the upward trend (See Appendix A) of the average NO_2 concentration is attributed to the significant variation in the two monthly averages beginning in spring 1968. This coincides with the conversion of five inch fume line headers to eight inch headers from the Tri-houses to the recoveries which eliminated the necessity of releasing NO_2 fumes during pressure build-ups. However, the net result may have been to overload the recoveries beyond absorption capacity and cause higher than normal emissions of NO_2.

(3) During the second production period, all stations show a significant trend downward. Station Pond 5 had the largest change in NO_2 levels with average decreasing from 0.151 ppm to 0.080 ppm. Two factors bear which could have resulted in lowering the average levels.

(a) Production at the plant was down to five TNT lines for the last nine months of the period.

(b) Direct control of NO_x emissions was enhanced with the installation of additional bubble cap towers at four of the six acid and fume recoveries.

(c) The installation of the bubble cap towers was completed in March 1970; whereas, the plant reduced production of five TNT lines on 15 May 1970. Although insufficient data were available to determine the significance of additional towers, a review of the monthly averages (Appendix A) would indicate that the downward trend of the monthly averages is more directly related to the decrease in production.

(5) The trend downward continued during the third production period, however, to a less significant degree. Again the most significant decrease occurred at Pond 5 where the average monthly level lowered from 0.092 ppm to 0.062 ppm. There is no apparent reason for the lower average values during this 11 month period. No pollution control efforts were completed and production levels at three TNT lines operating were constant. This is reflected at Station Admin where no significant trend in the monthly averages is discernible. At Stations R&G and Gate 20 the trend cannot be said to be significant because the least squares equation of $X = \bar{X} \pm b\ h$ resolves to 0.067 ± 0.010. This value 0.010 ppm NO_2 corresponds to the lower detactable limit of the sampling equipment.

(6) Figure 3 displays the relationship of production level and the average monthly NO_2 level. The production level is indicated by number of TNT lines. The average NO_2 level is the result of combining the monthly average by production period for all four sampling stations. The least

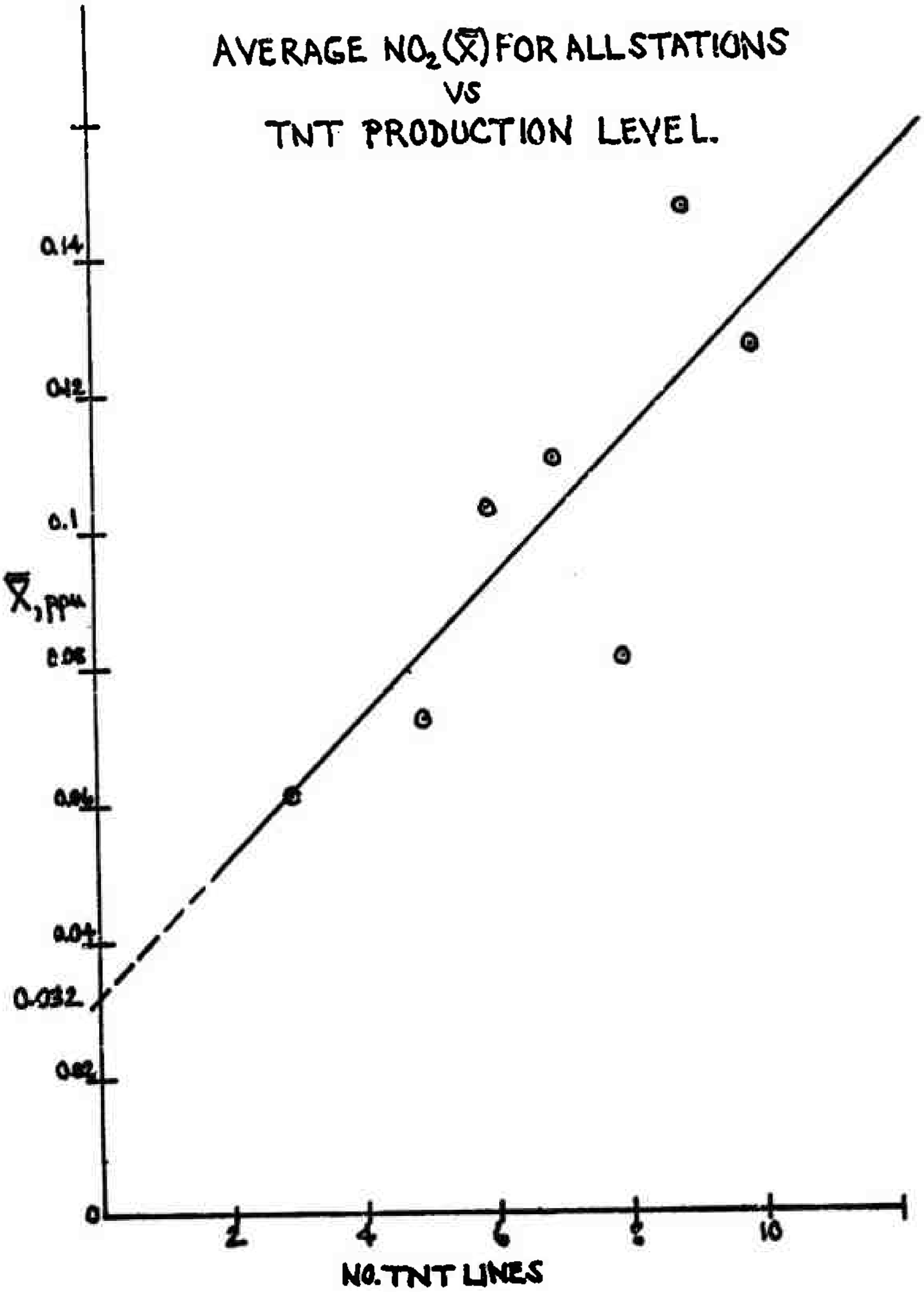


FIGURE 3. Relationship of Production Level and Average Monthly NO_2 Level

squares trend analysis would indicate that the air quality standard for NO_2 of 0.05 ppm annual arithmetic mean can be met when no more than two TNT lines using the batch-type process are operating. The trend line would also indicate that the average NO_2 level for the four stations would be 0.032 ppm if production of TNT were completely halted. A review of the monthly reports for January - May 1972 indicate the following.

TABLE 6

MONTH	NUMBER OF TNT LINES	AVERAGE NO_2, ppm
January	2	0.046
February	2	0.051
March	3	0.055
April	3	0.059
May	3	0.042

c. Particulates.

(1) Table 7 illustrates the annual geometric for the five-year period. Except for lapses resulting from minor maintenance, the sampling for the five years was continuous at all four stations. The annual means indicate that levels of particulate matter exceed the Federal secondary standard of 60 $\mu g/M^3$ annual geometric mean. However, statistical analysis of the data mitigate this finding.

TABLE 7
PARTICULATE $\mu g/M^3$
ANNUAL GEOMETRIC MEAN
CALENDAR YEAR

STATION	1967	1968	1969	1970	1971
Admin	96	116	77	68	86
Pond 5	130	145	122	88	72
R&G	105	95	78	72	64
Gate 20	74	64	59	80	66
Average	101	105	84	77	72

(2) The arithmetic mean by production level (used for trend analysis) are listed in Table 8. The number of TNT lines operating during the three production periods are 8-10, 5-7, and 3 lines respectively.

TABLE 8

PARTICULATE $\mu g/M^3$
PRODUCTION PERIOD AVERAGES

STATION	FIRST	SECOND	THIRD
Admin	122	93	95
Pond 5	139	121	111
R&G	106	94	108
Gate 20	85	91	89
Average	113	100	101

(3) The largest variability in the data for particulates is again found at Pond 5. The standard deviation (S) estimated from the average monthly range is listed for each station in Table 9 by production period. The upper control limit (UCL) and lower control limit (LCL) representing 3S about the mean are also listed. These control limits include 99.73% of all the monthly ranges found within each period.

TABLE 9

PARTICULATE $\mu g/M^3$
PRODUCTION PERIOD

STATION	FIRST		SECOND		THIRD	
	S	UCL;LCL	S	UCL;LCL	S	UCL;LCL
Admin	81	465;113	57	323; 48	48	263; 39
Pond 5	96	555;135	104	535; 87	64	356; 53
R&G	77	447;108	69	389; 58	64	354; 53
Gate 20	61	353; 85	47	268; 40	43	235; 35

(4) Pollution abatement for particulate matter was accomplished in the following sequence. All actions to control or abate the emissions occurred during the first production period.

(a) Farmers Chemical Associates, Incorporated, powerhouse converted to gas and oil fuel - June 1967.

(b) Particulate scrubbers installed in red water incinerator stacks - June 1968.

(c) Convert red water incinerators to gas and oil fuel - July 1969.

(d) Shut down operation of red water incinerators - September 1969.

(5) Table 10 lists the slopes of the least square trend lines for the four stations by production period. As mentioned above, all control efforts for particulate emissions were accomplished during the first production period. The trend lines with the monthly averages are illustrated in Appendix B for the first and third production periods. No trends are indicated for the second period.

TABLE 10

PARTICULATE
PRODUCTION PERIOD TRENDS

STATION	FIRST	SECOND	THIRD
Admin	-2.7	0.3	-6.4
Pond 5	1.1	0.7	-8.8
R&G	-1.8	1.3	-10.4
Gate 20	-1.9	0.2	-6.3

(a) All Stations except Pond 5 reflect a slight downward trend during the first production period. No doubt this resulted from installation of abatement measures for particulates. The largest decrease during the period occurred at Station Admin where the average two-monthly value decreased from 143 mg/M^3 to 101 mg/M^3. Nonetheless, the average level of particulate remained high in comparison to the air quality standard.

(b) No trend is discernible during the second production period. Although Station R&G reflects a slight increase from 86 to 102 μg/M^3, this small increase would not be measurable considering the sampling accuracy of the Hi-Volume sampler. Further, no pollution control actions were implemented during the period and a downward trend would be expected with a decrease in plant activity. Production levels were at seven TNT lines operating at the beginning of the period; however, the level dropped to five TNT lines after five months and remained at that level for the remaining eight months of the period.

(c) Significant decreases are reflected during the third production period. The most significant occurred at Station R&G where the average particulate level decreased from 160 mg/M³ to 56 mg/M³ even though production levels were constant and no new controls were instituted. However, one action was taken which was expected to lower the averages. Following the publication of the Federal air quality standards in April 1971, personnel from VAAP contacted the USAEHA for suggestions on meeting the standards for particulate. It was suggested that the sampling height be raised from the existing level of four feet above the ground to 11 feet above the ground. The higher sampling level conforms to accepted practices and apparently contributed to a reduction in the data.

(d) The average values for particulate do not reflect the decrease in production activity as the values for NO_2. The reason for this may be found in the plant modernization which began in 1970. This modernization required a considerable amount of earth moving and heavy traffic over unpaved roads which would result in the smaller particulate becoming airborne and may have caused the levels of particulate to remain excessively high. A list of the construction activities follows: New open burning pad - started March 1970; completed April 1971; New Acid area - started March 1971; Three continuous TNT lines - started August 1971 (earth moving between August and November); Computer facility - started July 1971, completed Spring 1972.

d. <u>Sulfur Dioxide</u>.

(1) Table 11 lists the annual arithmetic means for the five year period. As noted earlier the data generated at Station Admin and Pond 5 were declared invalid for 1967 and part of 1968. The annual means indicate exceptional control of SO_2 emissions and are well within the air quality standard of 0.02 ppm annual arithmetic mean.

TABLE 11

SULFUR DIOXIDE (PPM)
ANNUAL ARITHMETIC MEAN
CALENDAR YEAR

STATION	1967	1968	1969	1970	1971
Admin	--	0.006	0.007	0.005	0.005
Pond 5	--	0.005	0.006	0.006	0.005
R&G	0.008	0.006	0.006	0.007	0.005
Gate 20	0.010	0.009	0.011	0.008	0.005
Average	--	0.007	0.008	0.007	0.005

(2) Arithmetic means were not resolved by production period because a least squares trend analysis was not required. Control measures completed prior to start-up or during the first production period resulted in the low ambient SO_2 levels. Short term levels of SO_2 were also well within air quality standards. Table 12 describes the variability found in the air quality data. The standard deviations, S, are estimated from the average monthly range during the production period. The upper control limits (UCL) compare with the air quality standard of 0.1 ppm maximum 24 hour average not to be exceeded. The upper limits and the lower control limits (LCL) represent 3S about the mean and include 99.73% of all monthly ranges.

TABLE 12

SULFUR DIOXIOE (PPM)
PRODUCTION PERIOD

STATION	FIRST		SECOND		THIRD	
	S	UCL ; LCL	S	UCL ; LCL	S	UCL ; LCL
Admin	0.008	0.045;0.007	0.002	0.013;0.002	0.002	0.009;0.001
Pond 5	0.004	0.020;0.002	0.002	0.008;0.002	0.003	0.014;0.002
R&G	0.008	0.047;0.011	0.006	0.034;0.006	0.001	0.007;0.001
Gate 20	0.017	0.097;0.023	0.007	0.041;0.013	0.004	0.019;0.003

(3) The control measures which directly affected the emission of SO_2 are listed below:

(a) Farmers Chemical Associate, Incorporated, powerhouse converted to gas and oil fuel - June 1967.

(b) Convert red water incinerators to gas and oil fuel - July 1969.

(c) Shut down operation of red water incinerators - September 1969.

(d) Modification of sellite plant absorption towers - April 1970.

e. Acid Mist (H_2SO_4).

(1) Sampling was performed for acid mist from the start of the current reactivation. However, a satisfactory sampling method was not developed until July 1969. The sampling technique is "state of the art" and represents a composite sample for total acidity, not specifically acid mist. This analysis does not include any data generated prior to July 1969. Most of the abatement measures for acid mist were completed prior to July 1969 resulting in the low average values listed in Table 13. The values compare favorably with the guidelines of 0.015 ppm (0.06 mg/M^3) average value not to be exceeded. No trend analysis was indicated.

TABLE 13

ACID MIST (H_2SO_4, mg/M^3)
CALENDAR YEAR

STATION	1969	1970	1971
Admin	0.01	0.01	0.005
Pond 5	0.012	0.013	0.006
R&G	0.012	0.012	0.005
Gate 20	0.011	0.010	0.005

(2) Practically all abatement efforts would affectively lower the acid mist values. Those that directly affect the data are listed below:

(a) Rehabilitation of SAC electrostatic precipitators - 1967.

(b) Install Brink mist eliminator at sellite plant - February 1968.

(c) Install York demisters on Mahon Fog Filters at SAC - January 1969.

(d) Overhaul SAC electrostatic precipitators - November 1970.

f. Plant Modernization. A major modernization program was begun in 1971 which will result in a completely new facility for the production of TNT. All government operated processes are being replaced including the acid plants, recoveries, and other support facilities. The batch-type process for making TNT will eventually be replaced by a continuous process. Presently six continuous TNT lines have been approved for construction, three of which are approximately 80% complete. Ground was recently broken for the second set of three lines. Figure 4 describes the existing plant and the modernization program. It is expected that the emissions from

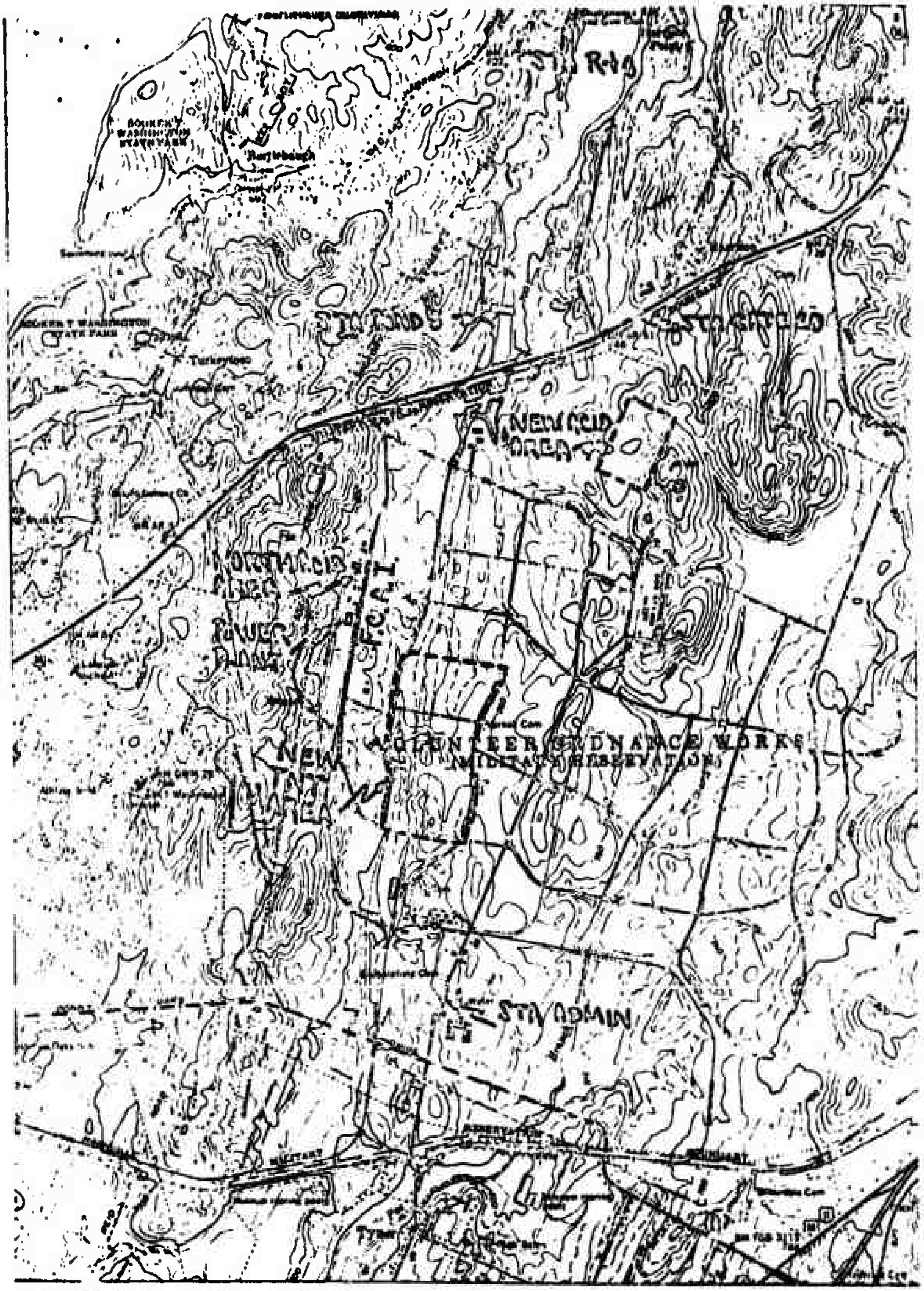


FIGURE 4 Plant Modernization

the continuous process will be controlled resulting in excellent air quality in an around the plant. The air sampling network will be expanded to eight sampling stations. This will be done to include areas of suspected high levels of pollution. Air sampling will include the four parameters discussed in this paper and at one selected location, sampling will be performed for oxidants, carbon monoxide, and hydrocarbons. This will provide data for all pollutants currently identified under the Federal standards. The government contractor, Atlas Chemical Industries, Incorporated, was recently purchased by Imperial Chemical Industries of America. This change was effective on 1 January 1972.

4. CONCLUSIONS. The operation of the batch-type process at VAAP has resulted in excessive pollution over the years of its operation. Recognizing the needs for environmental control significant progress has been made during this current reactivation. The data analysis indicated the following:

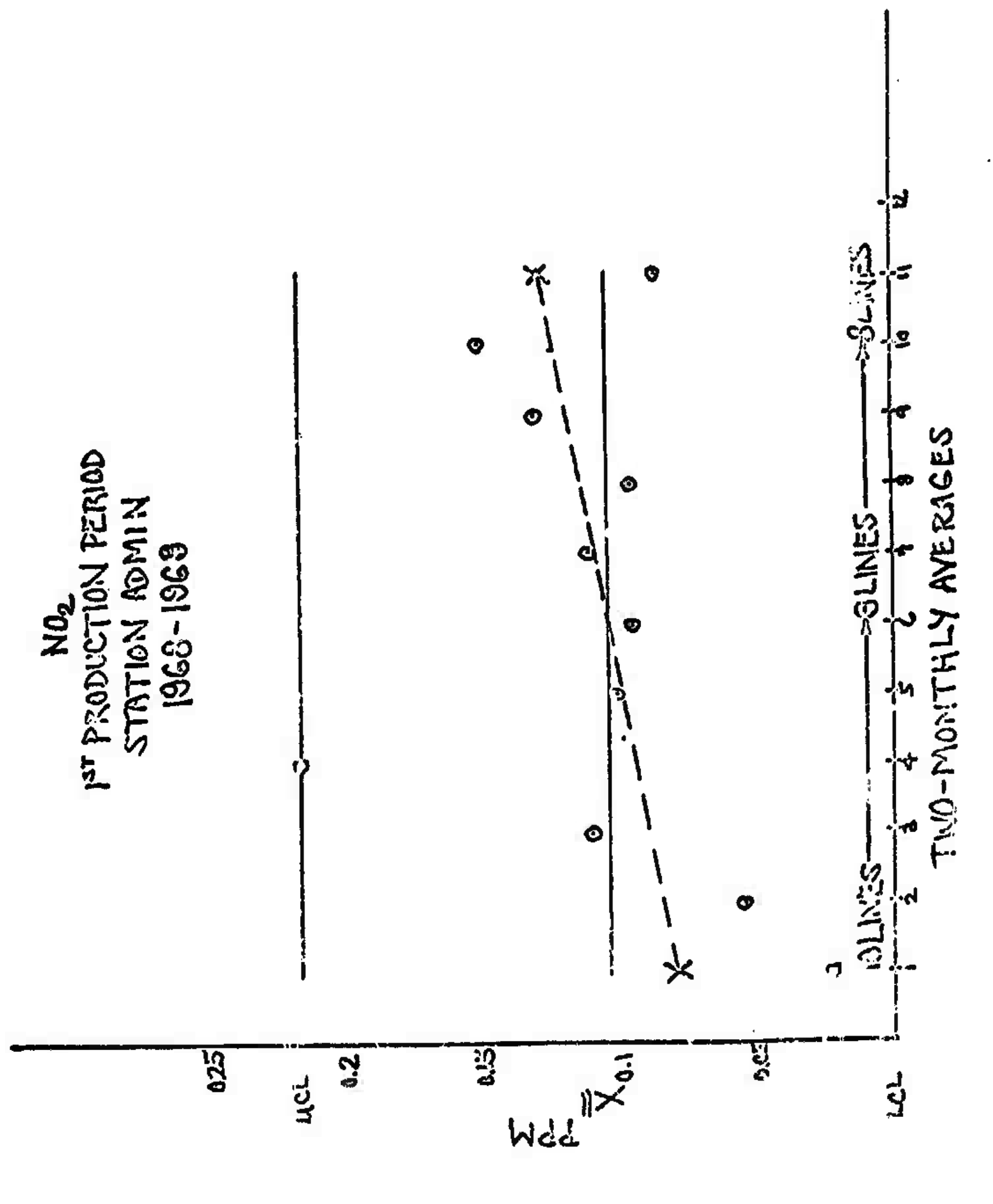
a. Control of the emissions of sulfur dioxide and acid mist early in the reactivation has resulted in ambient levels which are well within current air quality standards and guidelines.

b. Pollution abatement for particulates appears to have had marginal affect on ambient levels. Suspended particulate resulting from the current construction of new process equipment and open burning of explosive wastes probably influenced the high air quality levels during the 1970-1971 sampling periods.

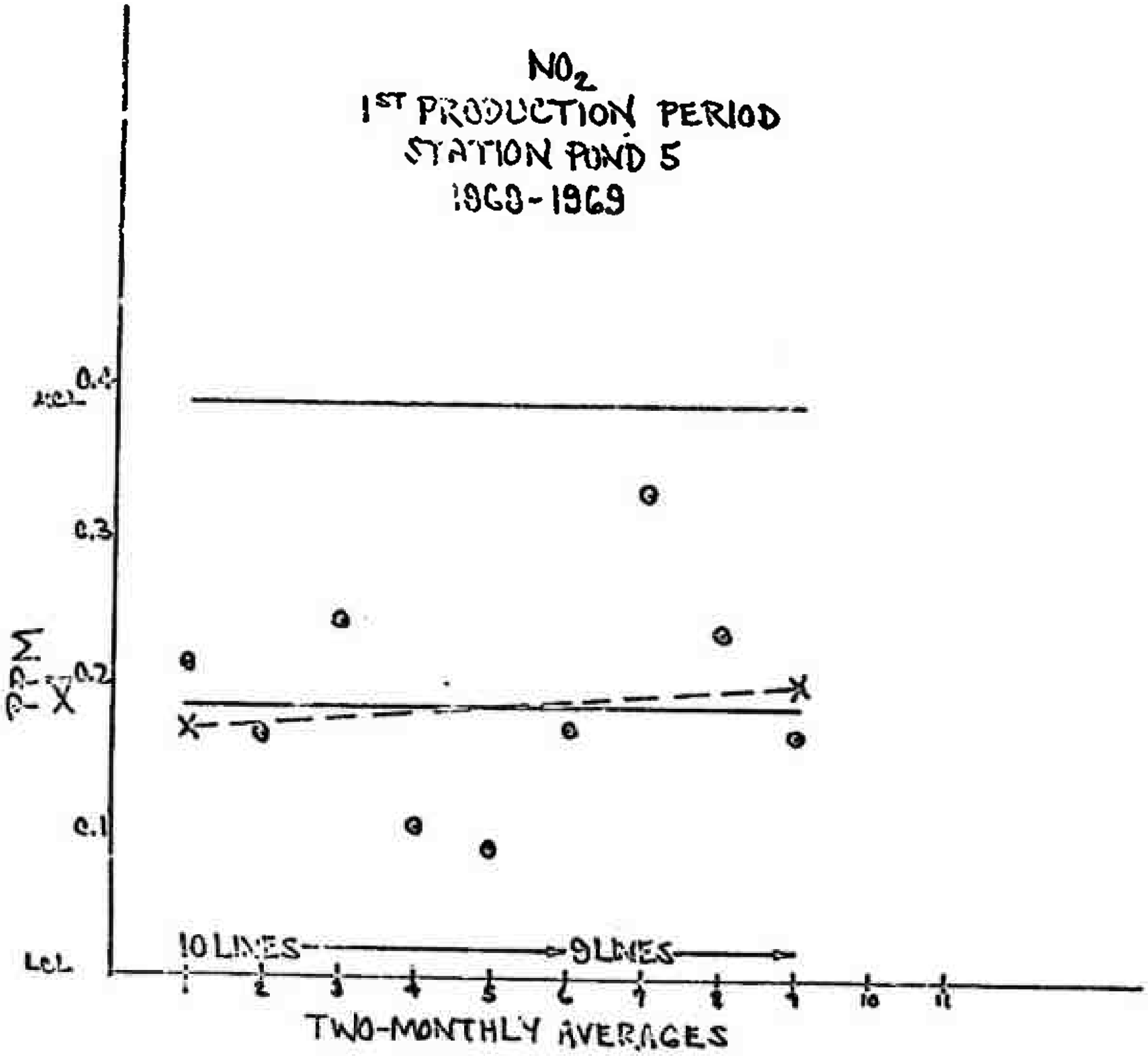
c. State of the art abatement measures for the emissions of nitrogen oxides are not adequate to control the effluent from the batch-type process. This has resulted in excessively high levels of nitrogen dioxide. Compliance with current standards is indicated when the plant is operating two TNT lines or less.

APPENDIX A

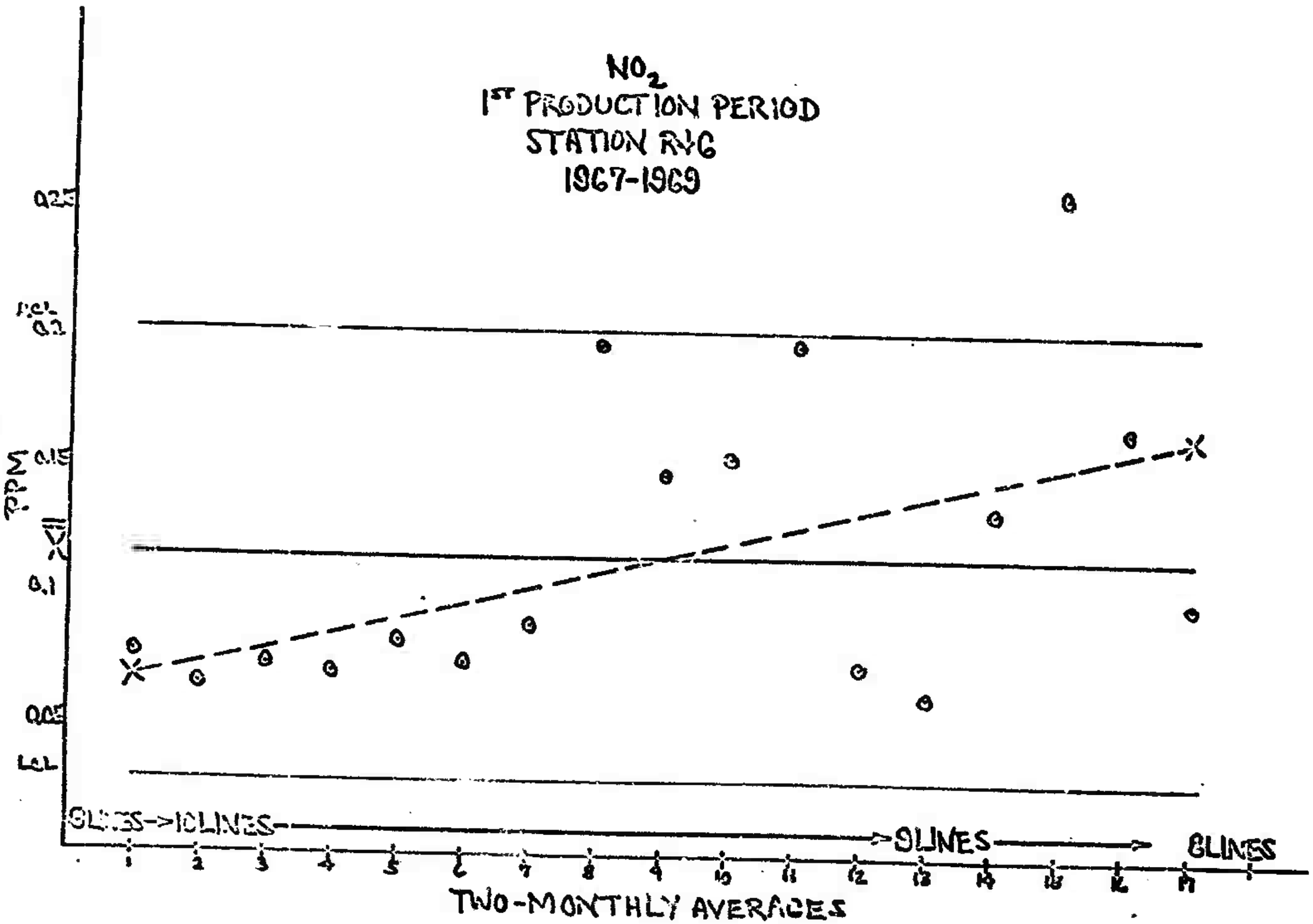
LEAST SQUARES TREND ANALYSIS NITROGEN DIOXIDE (NO_2)

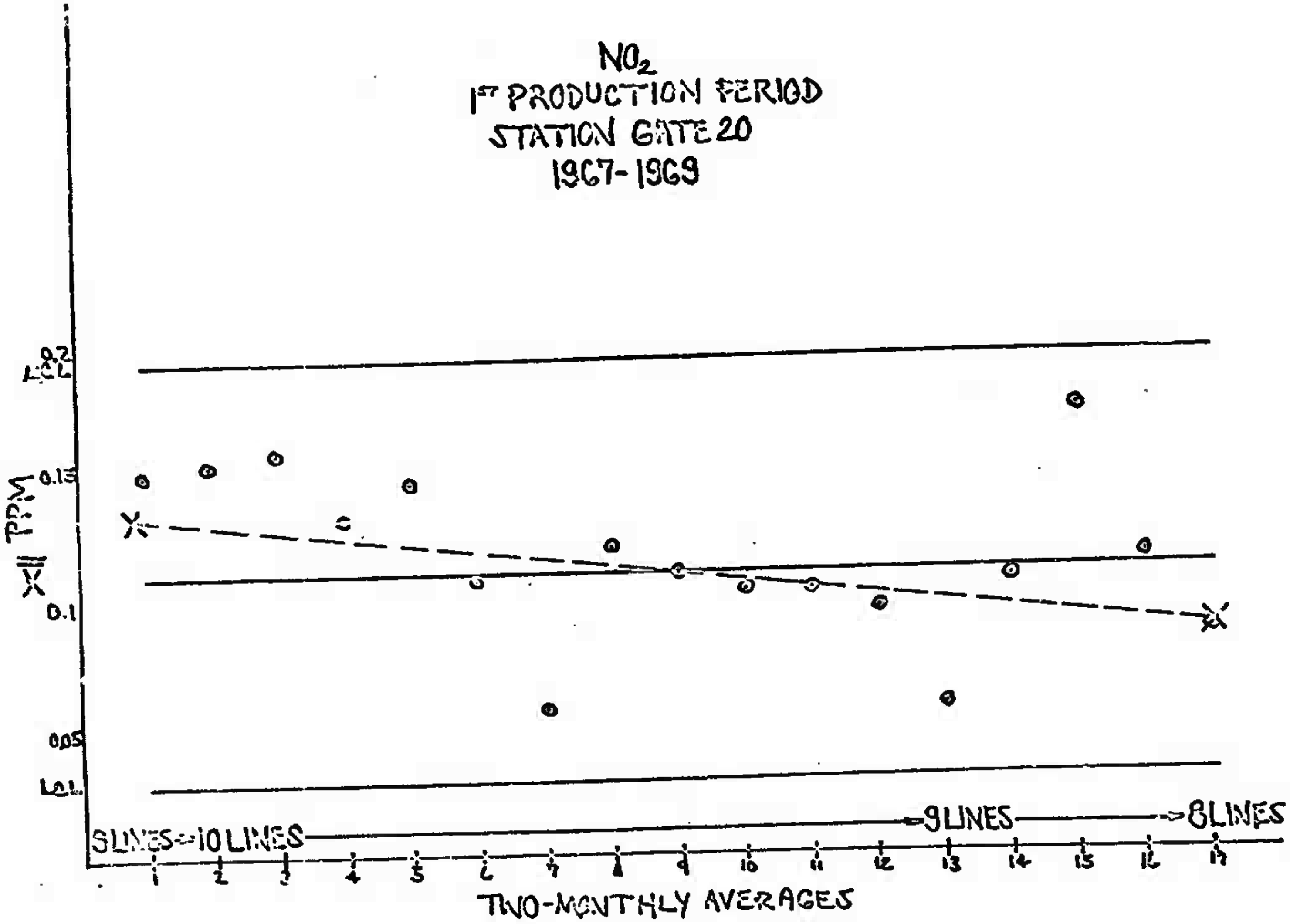


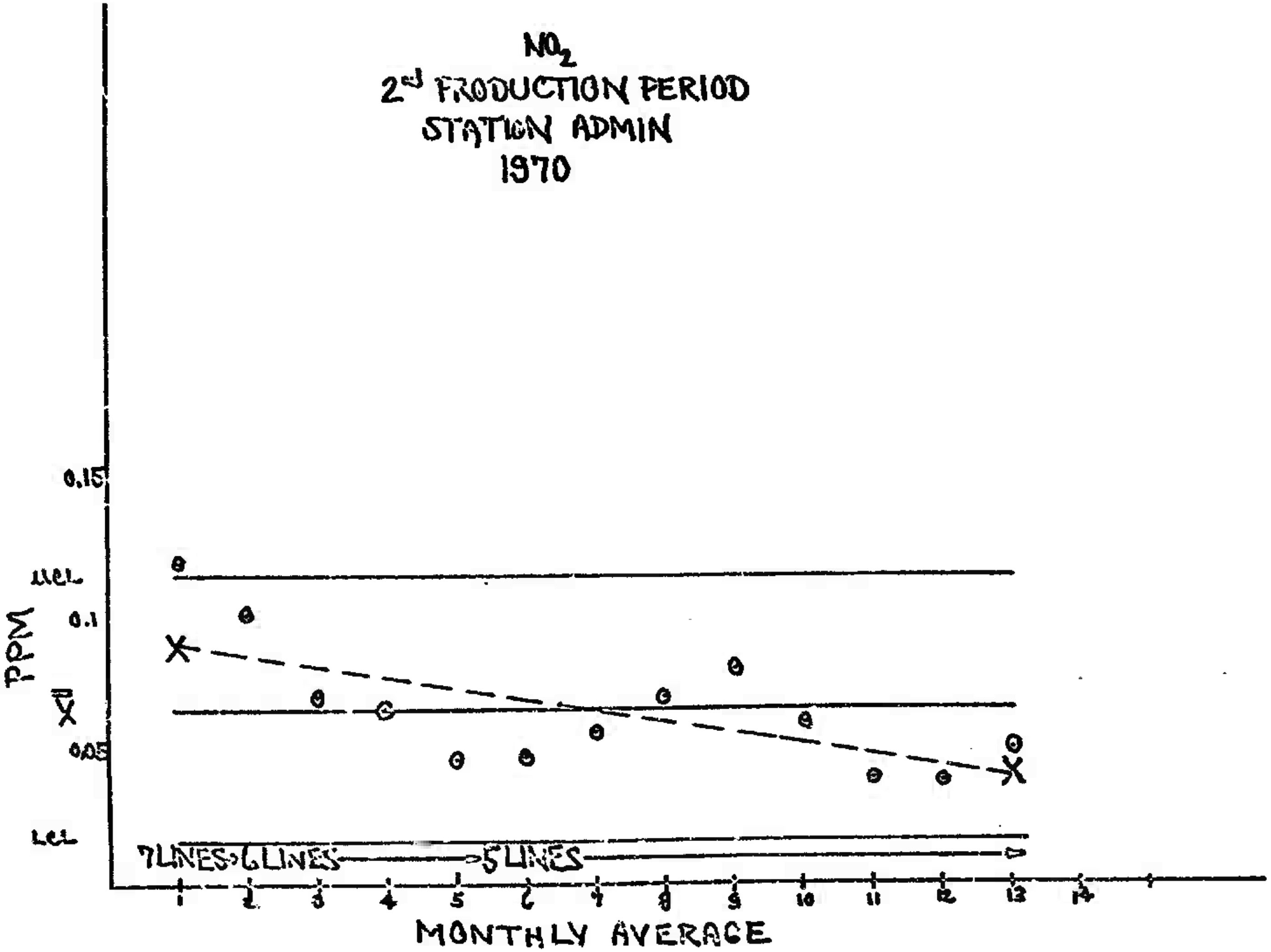
NO2
1ST PRODUCTION PERIOD
STATION ADMIN
1968-1969
PPM
UCL
LCL
0.25
0.2
0.15
0.1
TWO-MONTHLY AVERAGES



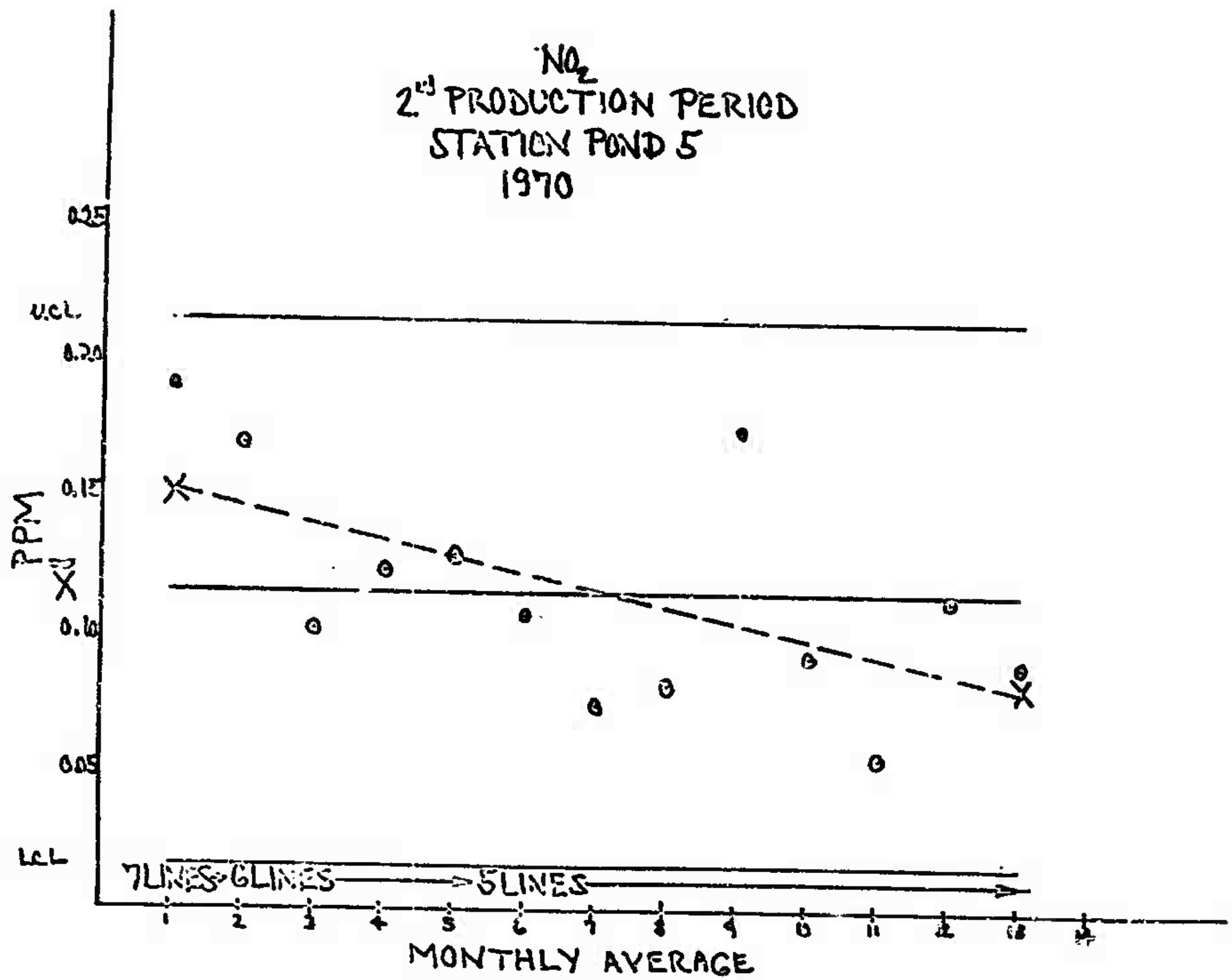
NO_2
1ST PRODUCTION PERIOD
STATION POND 5
1968-1969
UCL
0.4
0.3
0.2
0.1
PPM
$\bar{X}$
LCL
10 LINES
9 LINES
1
2
3
4
5
6
7
8
9
10
11
TWO-MONTHLY AVERAGES

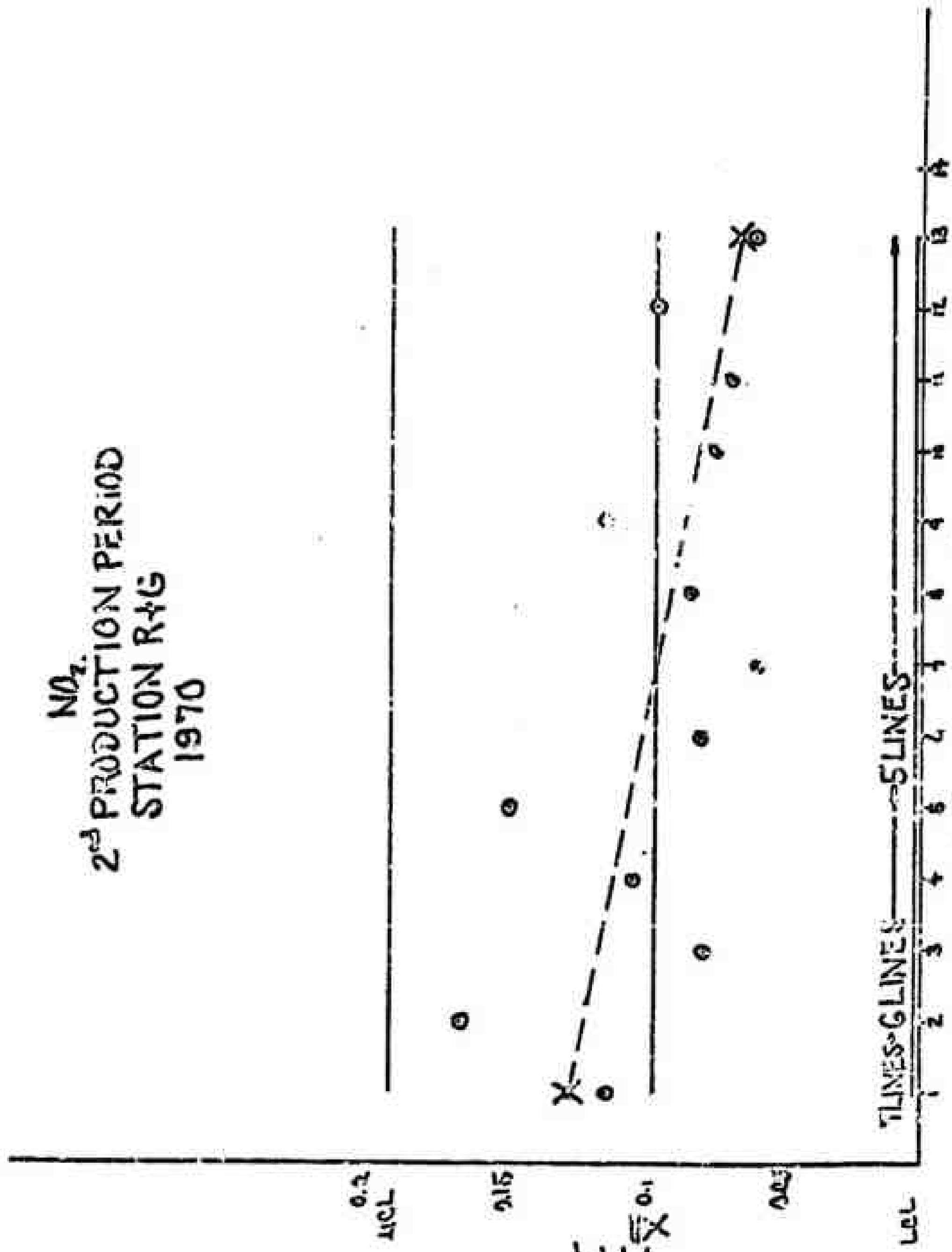

NO2
1ST PRODUCTION PERIOD
STATION R-G
1967-1969
0.25
UCL
0.2
0.15
PPM
0.1
0.05
LCL
10LINES
8LINES
8LINES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
TWO-MONTHLY AVERAGES


NO₂
1st PRODUCTION PERIOD
STATION GATE 20
1967-1969
0.2
U.C.L.
0.15
$\bar{\bar{X}}$ PPM
0.1
0.05
L.C.L.
8 LINES→10 LINES→9 LINES→8 LINES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
TWO-MONTHLY AVERAGES

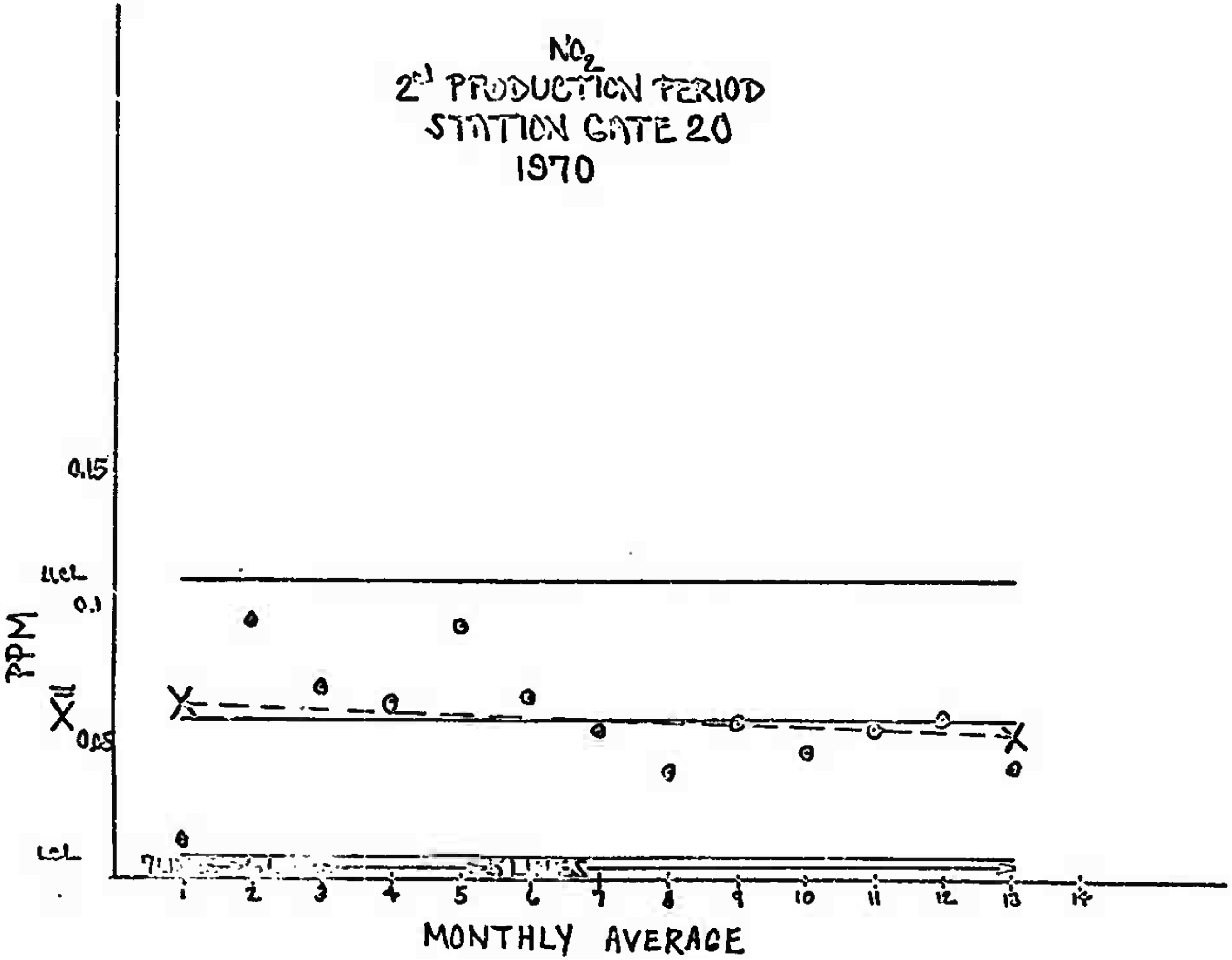

NO_2
2nd PRODUCTION PERIOD
STATION ADMIN
1970
0.15
UCL
0.1
PPM
$\bar{\bar{X}}$
0.05
LCL
7LINES
6LINES
5LINES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
MONTHLY AVERAGE

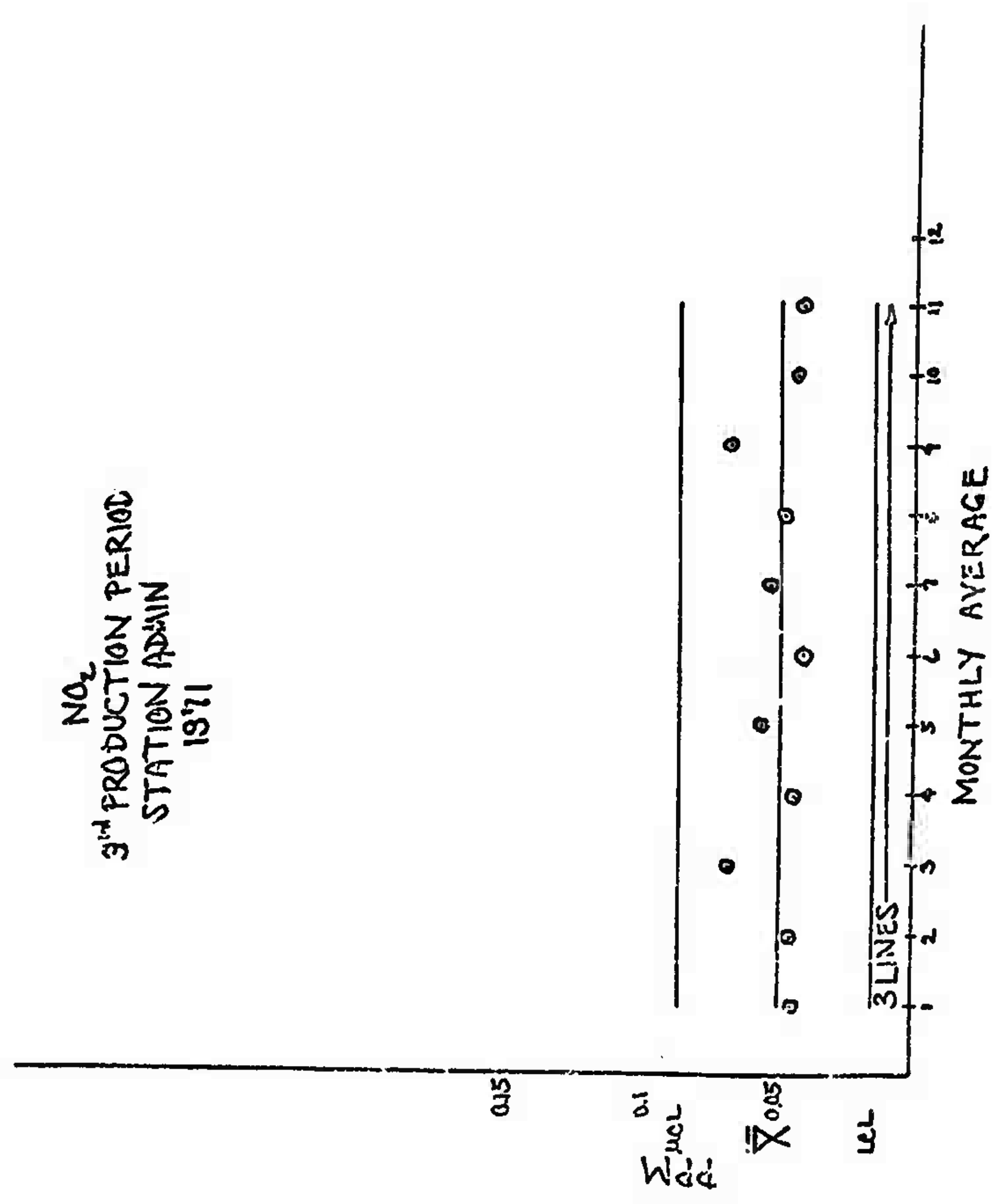
NO_2
2nd PRODUCTION PERIOD
STATION POND 5
1970

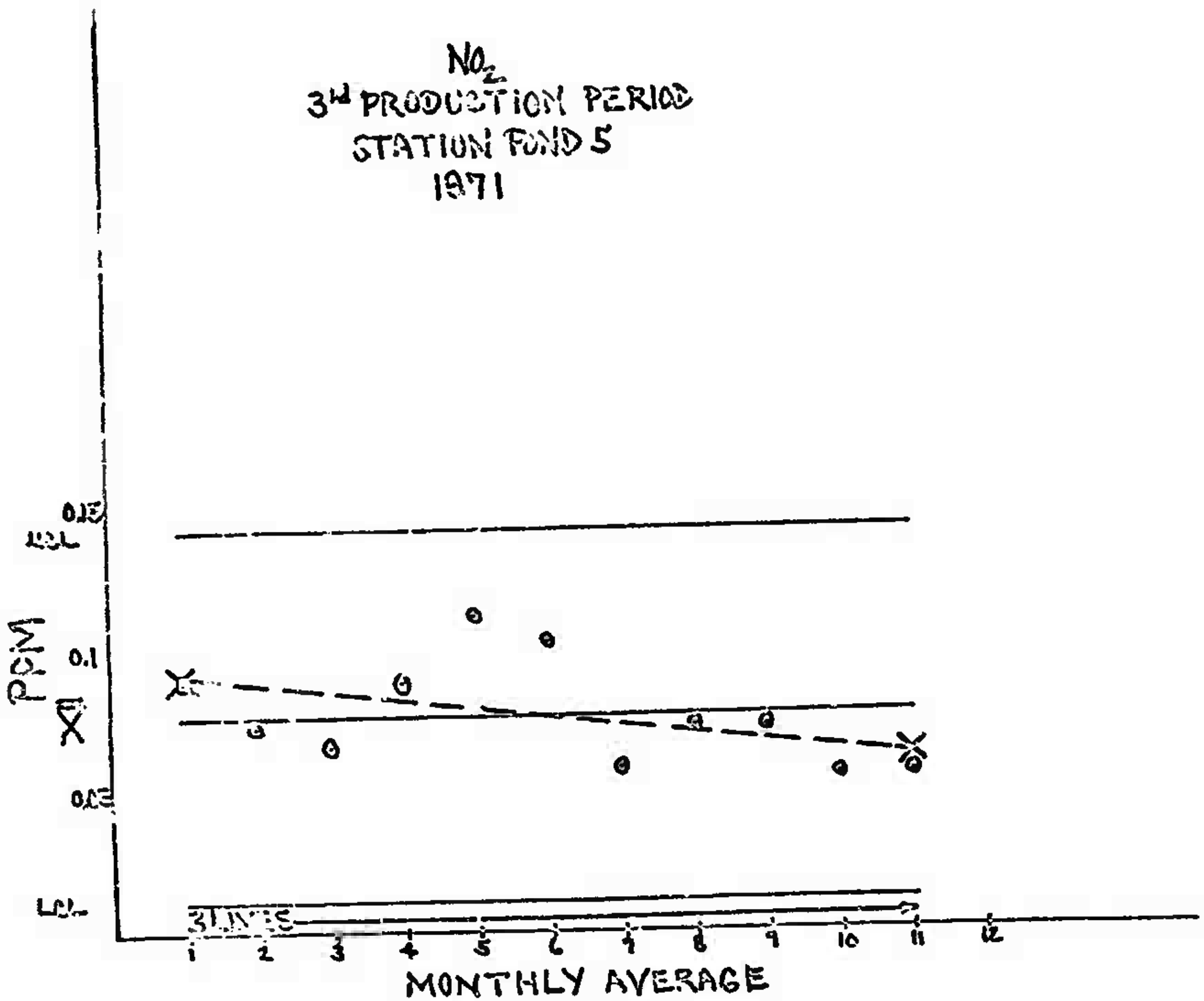


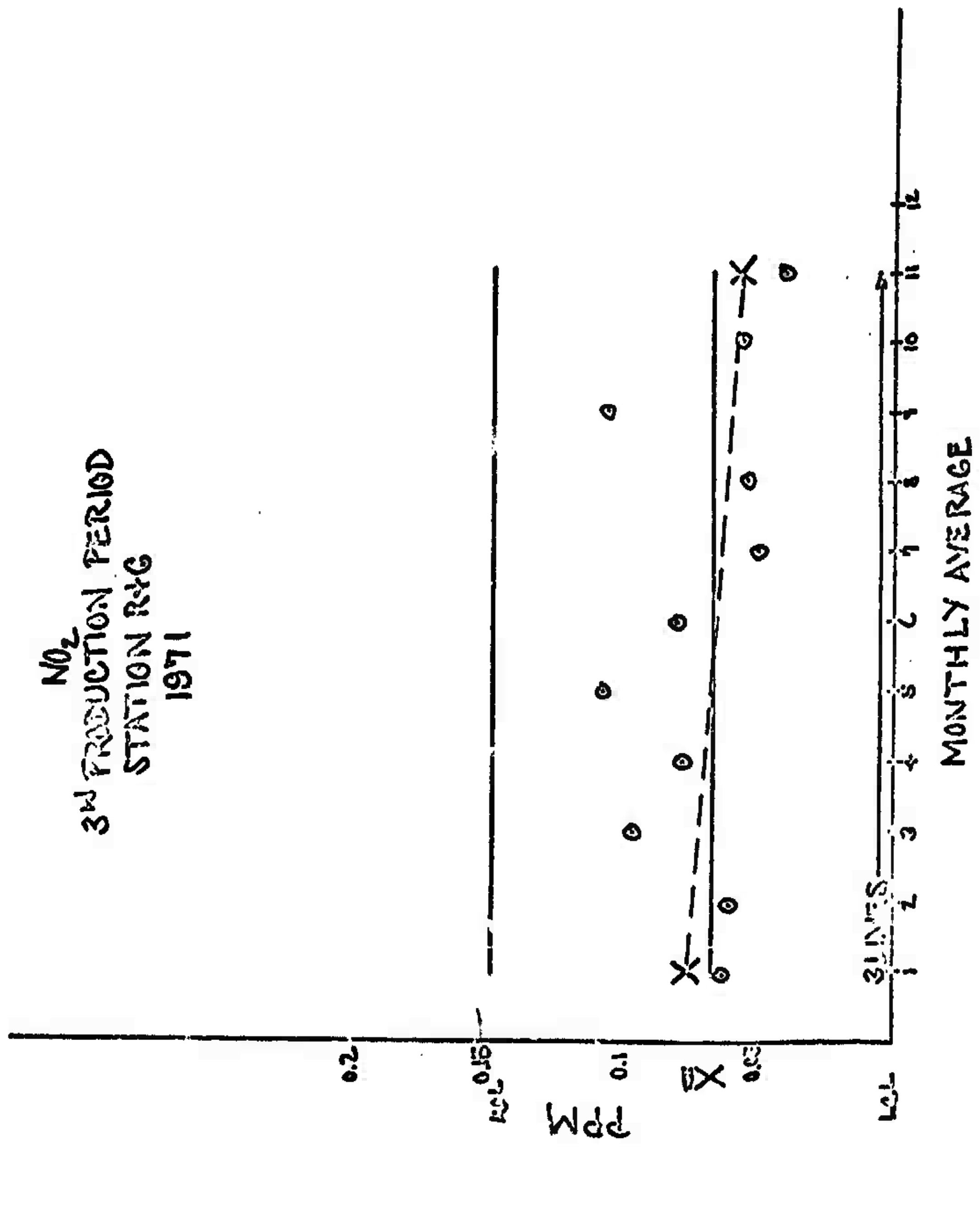


NO2
2nd PRODUCTION PERIOD
STATION R+G
1970
PPM X̄
0.2 UCL
0.15
0.1
0.05
LCL
7 LINES-6 LINES——5 LINES——
MONTHLY AVERAGE

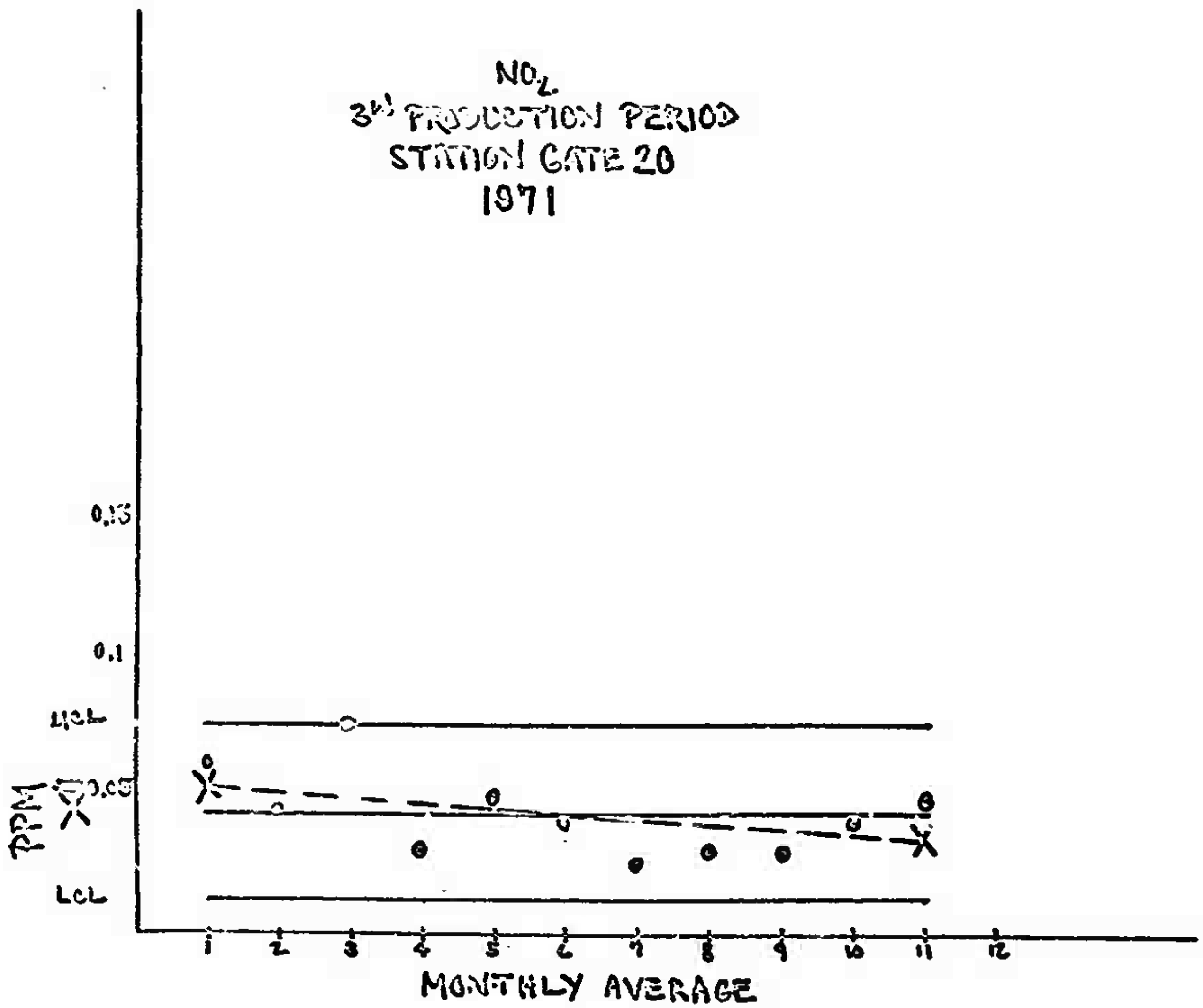

NO_2
2nd PRODUCTION PERIOD
STATION GATE 20
1970
0.15
UCL
0.1
PPM
$\bar{\bar{X}}$
0.05
LCL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
MONTHLY AVERAGE


NO2
3rd PRODUCTION PERIOD
STATION ADMIN
1971
PPM
UCL
X̄
LCL
0.15
0.1
0.05
3 LINES
1
2
3
4
5
6
7
8
9
10
11
12
MONTHLY AVERAGE


NO_2
3rd PRODUCTION PERIOD
STATION POND 5
1971
PPM
0.1
$\bar{X}$
UCL
LCL
1 2 3 4 5 6 7 8 9 10 11 12
MONTHLY AVERAGE

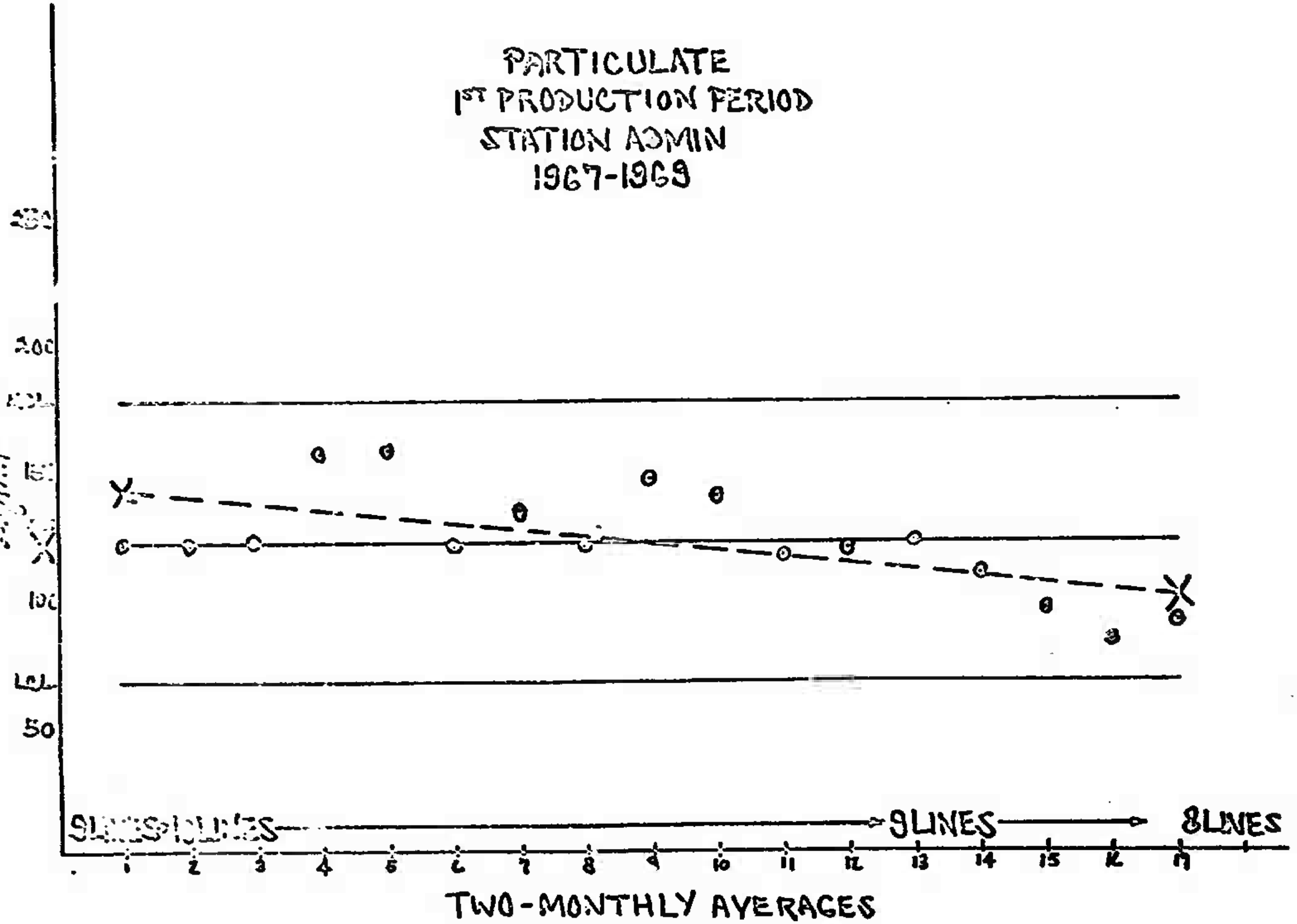


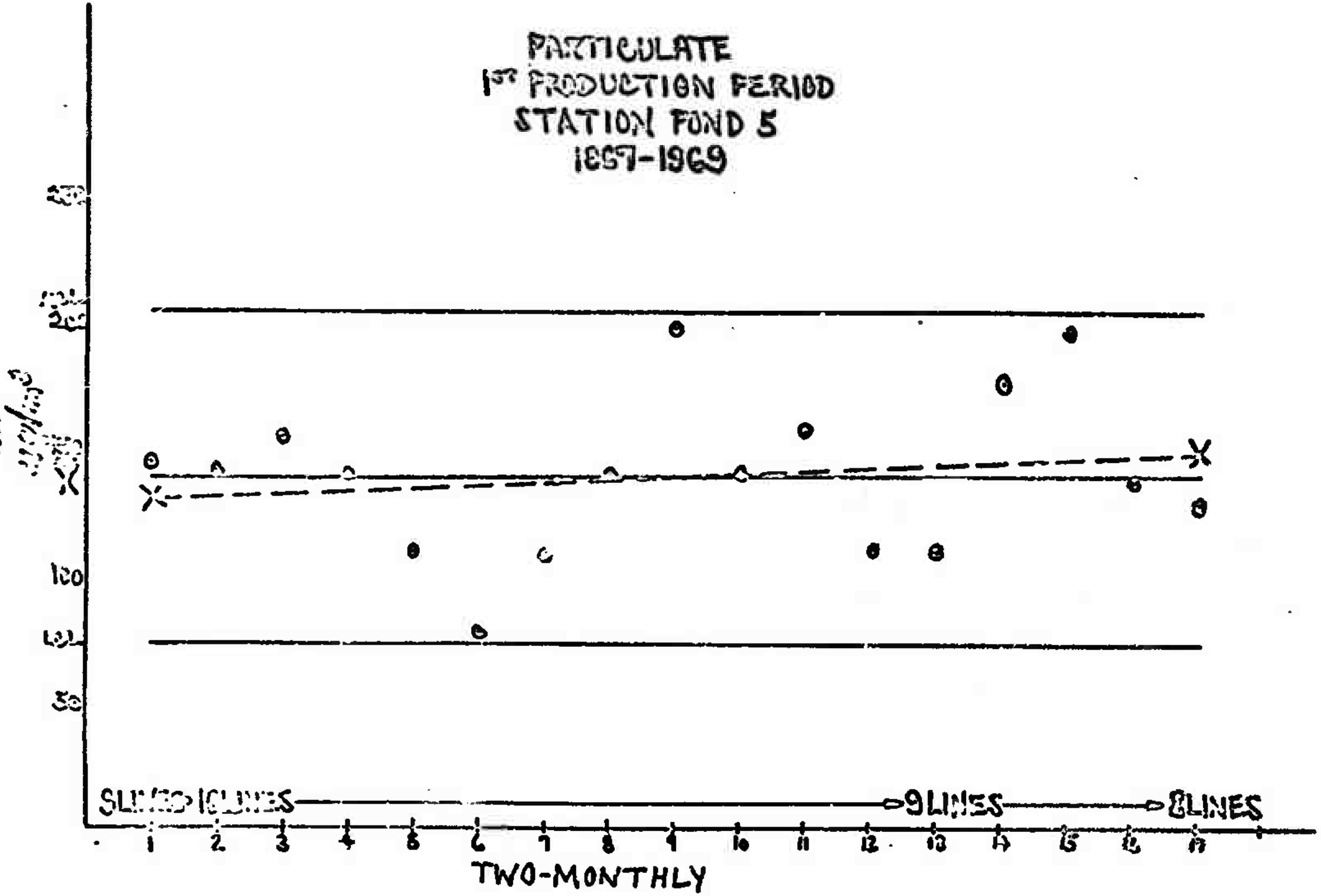
NO_2
3rd PRODUCTION PERIOD
STATION R&G
1971
PPM
0.2
ECL 0.15
0.1
X̄
0.05
LCL
1
2
3
4
5
6
7
8
9
10
11
12
3 UNITS
MONTHLY AVERAGE

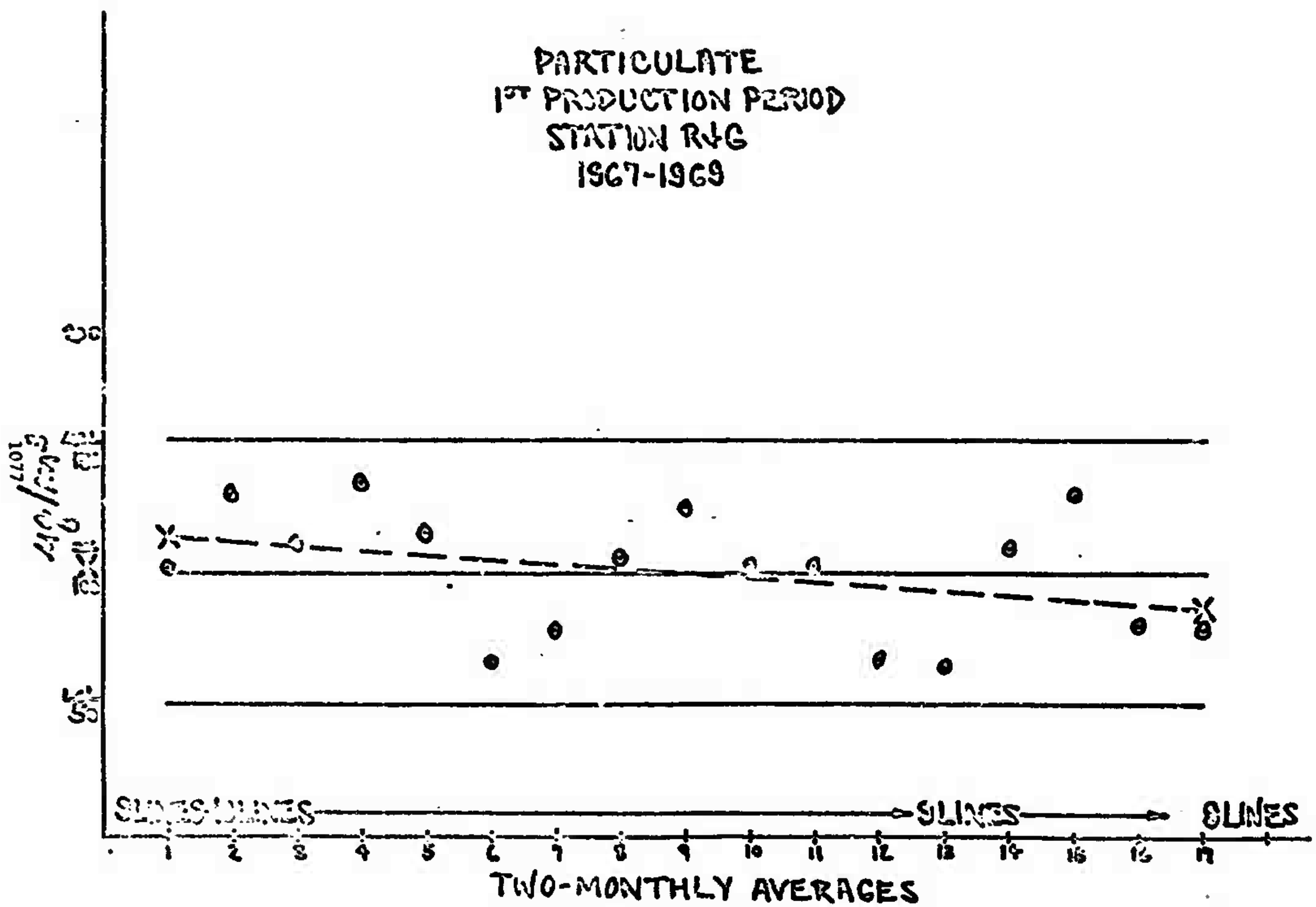

NO2
3rd PRODUCTION PERIOD
STATION GATE 20
1971
0.15
0.1
UCL
0.05
LCL
PPM
1
2
3
4
5
6
7
8
9
10
11
12
MONTHLY AVERAGE

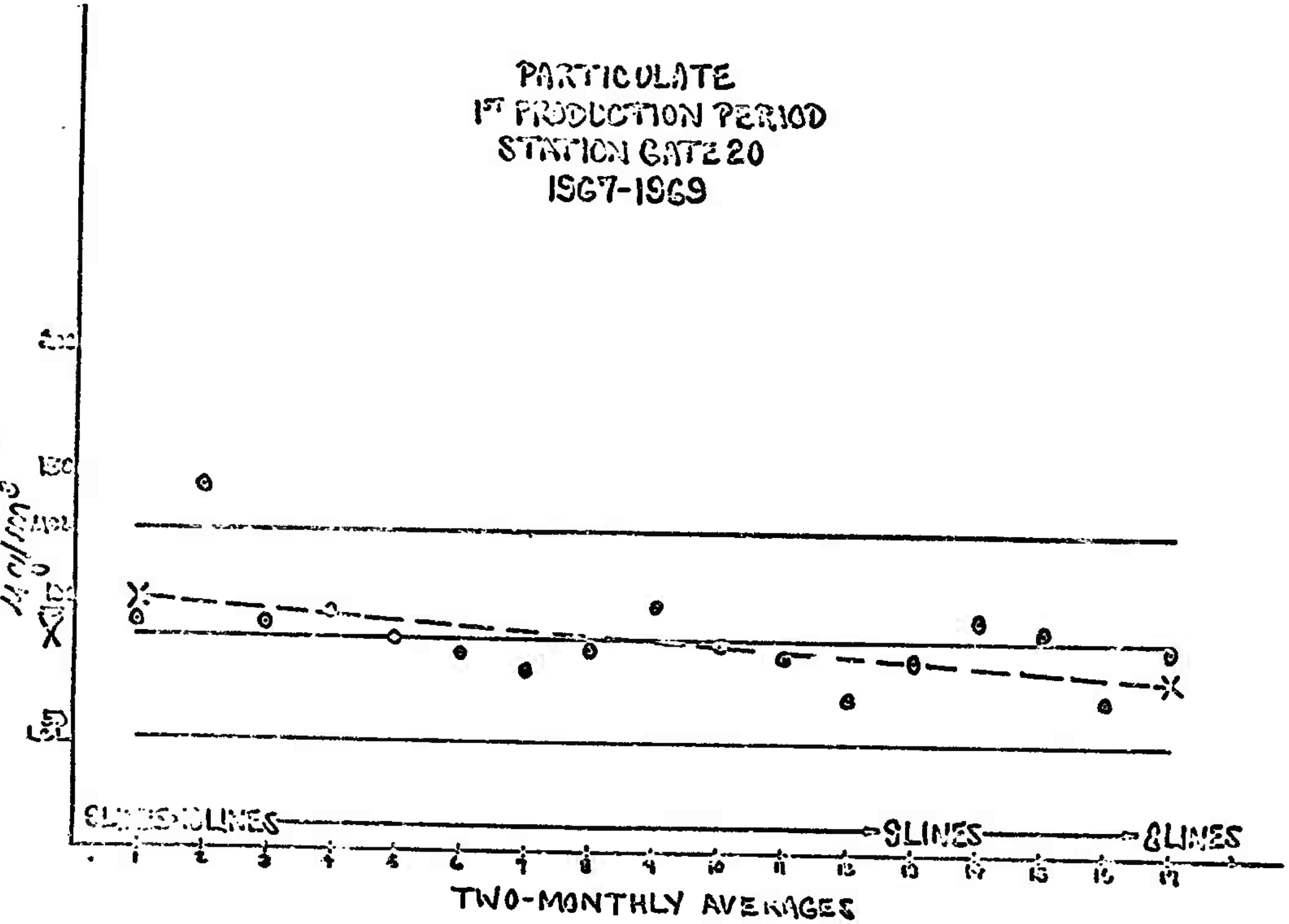
APPENDIX B

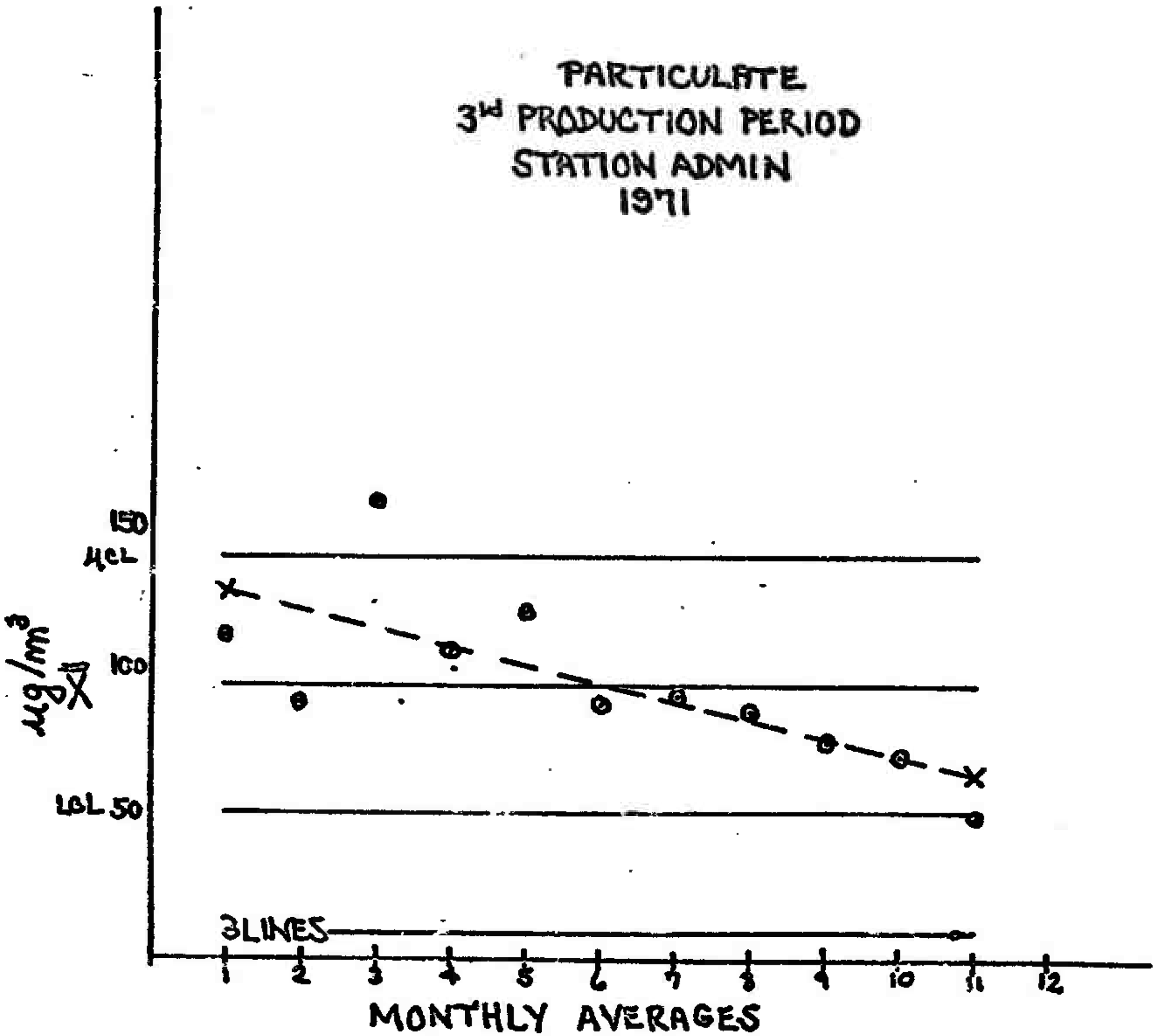
LEAST SQUARES TREND ANALYSIS PARTICULATE


PARTICULATE
1ST PRODUCTION PERIOD
STATION ADMIN
1967-1969
200
UCL
150
X
100
LCL
50
9LINES
8LINES
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
TWO-MONTHLY AVERAGES

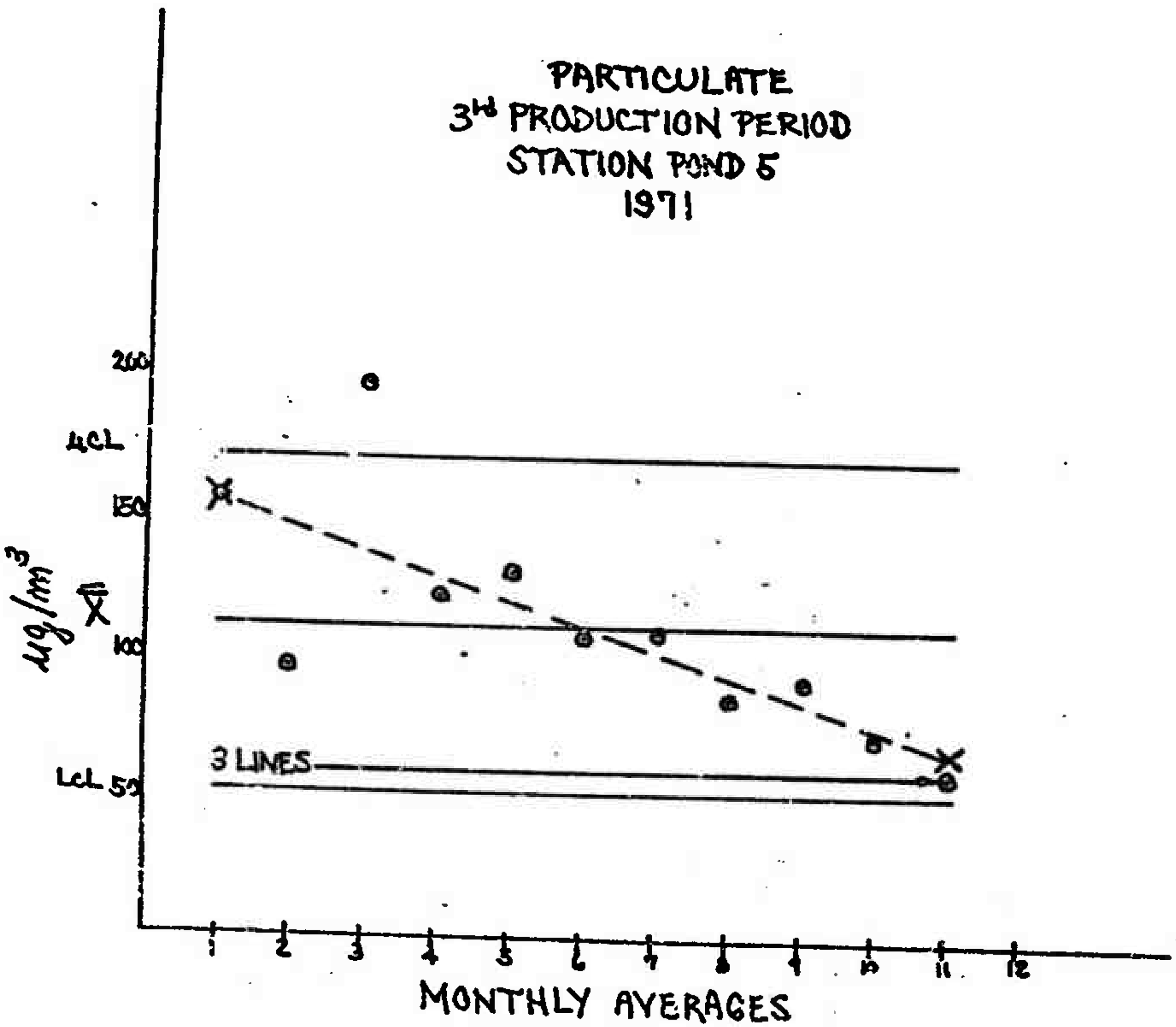

PARTICULATE
1ST PRODUCTION PERIOD
STATION POND 5
1967-1969
120
50
SLICED 10 LINES
9 LINES
8 LINES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
TWO-MONTHLY

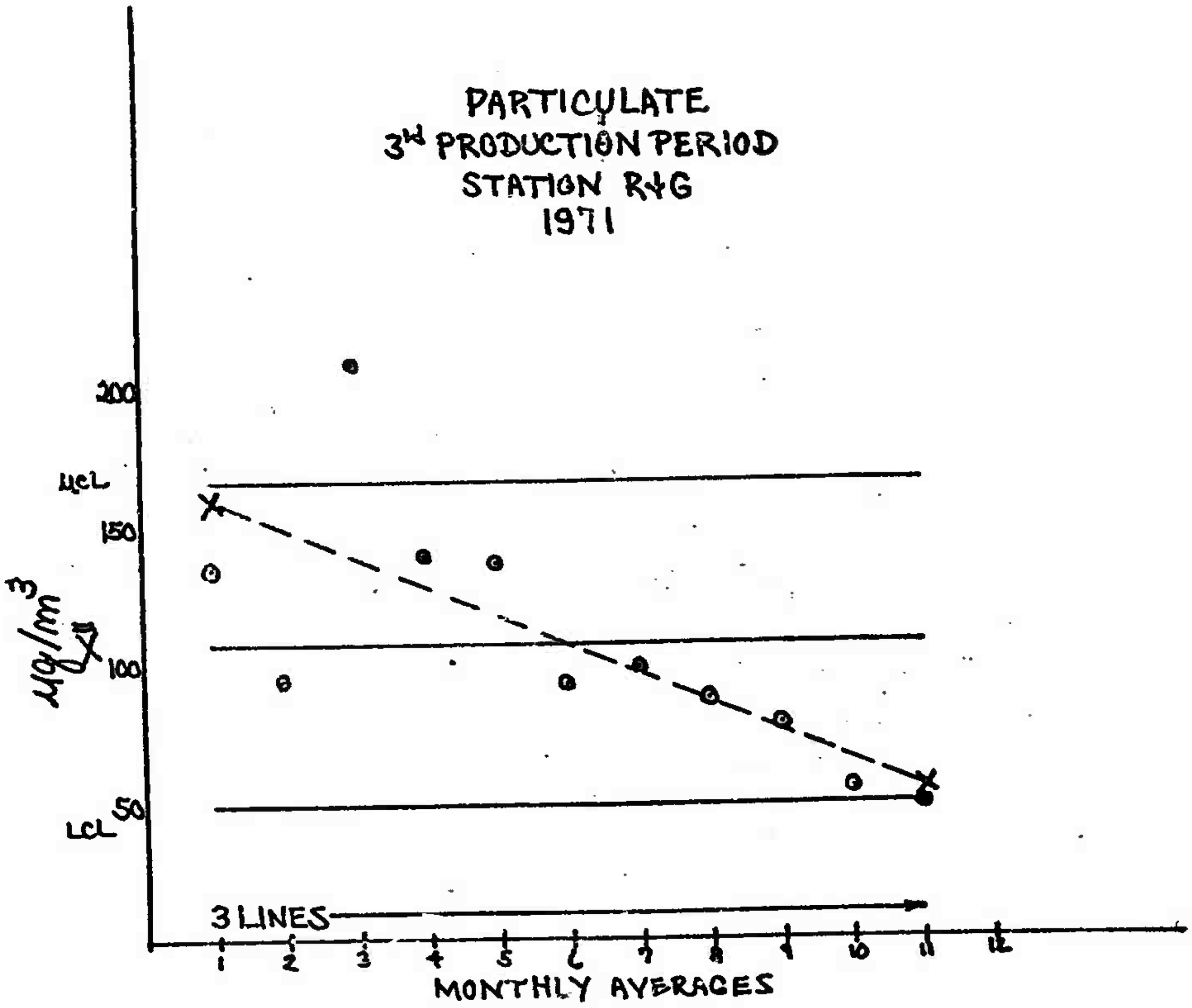

PARTICULATE
1ST PRODUCTION PERIOD
STATION RJG
1967-1969
TWO-MONTHLY AVERAGES
8LINES

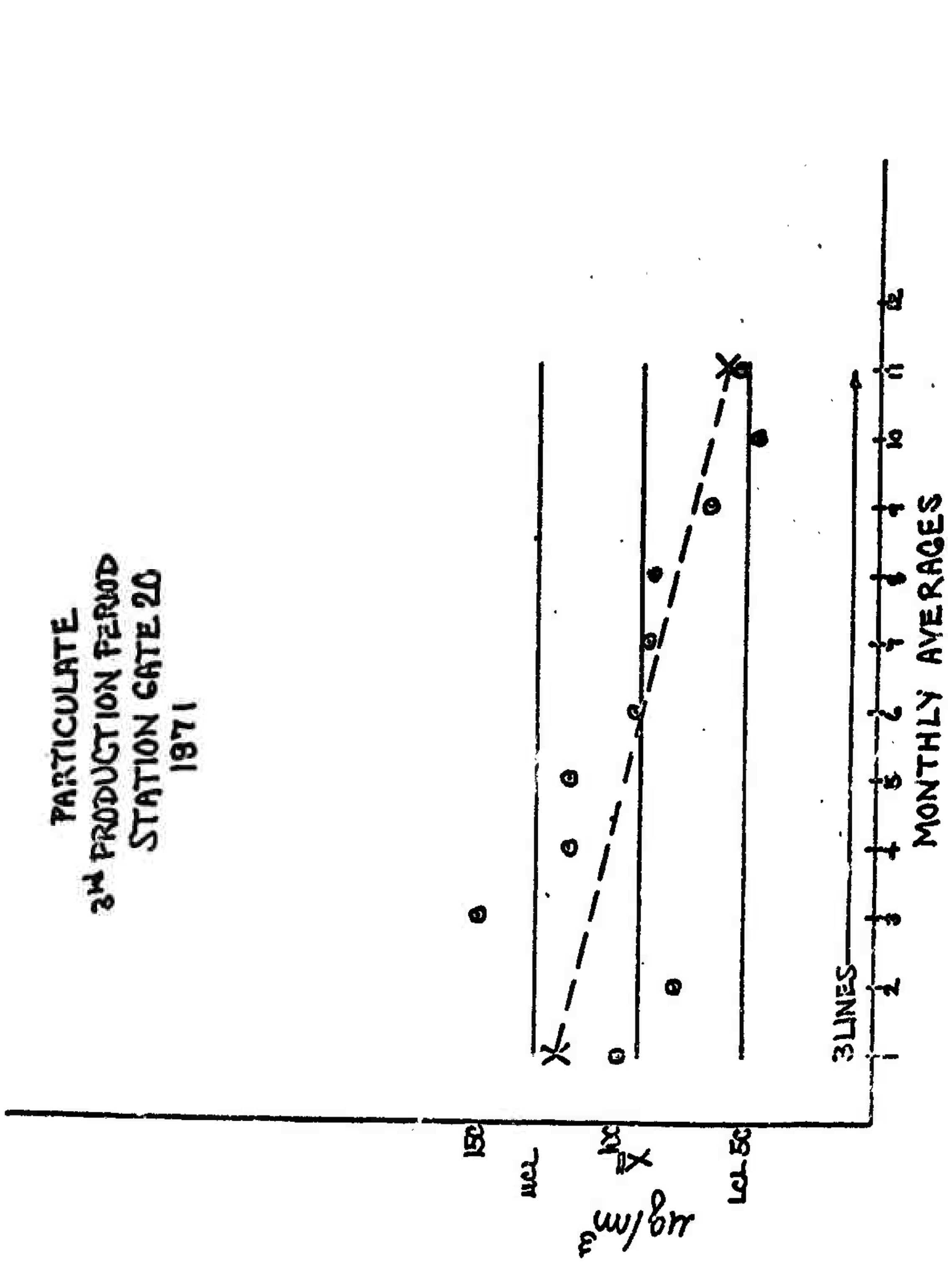

PARTICULATE
1ST PRODUCTION PERIOD
STATION GATE 20
1967-1969
150
SLINES
8LINES
TWO-MONTHLY AVERAGES



PARTICULATE
3rd PRODUCTION PERIOD
STATION ADMIN
1971
150
UCL
100
LCL 50
µg/m³ X̄
3 LINES
1 2 3 4 5 6 7 8 9 10 11 12
MONTHLY AVERAGES


PARTICULATE
3rd PRODUCTION PERIOD
STATION POND 5
1971
200
UCL
150
$\bar{X}$
100
LCL 50
$\mu g/m^3$
3 LINES
1
2
3
4
5
6
7
8
9
10
11
12
MONTHLY AVERAGES


PARTICULATE
3rd PRODUCTION PERIOD
STATION R&G
1971
200
UCL
150
100
LCL
50
$\mu g/m^3$
$\bar{\bar{X}}$
3 LINES
1 2 3 4 5 6 7 8 9 10 11 12
MONTHLY AVERAGES


PARTICULATE
3rd PRODUCTION PERIOD
STATION GATE 20
1971
150
UCL
100
X̄
LCL 50
μg/m³
3 LINES
1
2
3
4
5
6
7
8
9
10
11
12
MONTHLY AVERAGES

US ARMY ENVIRONMENTAL HYGIENE AGENCY WASTEWATER MONITORING ASSISTANCE AT ARMY MUNITIONS PRODUCTION FACILITIES

by
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Edgewood Arsenal, Maryland

INTRODUCTION.

America has become increasingly concerned with the degradation of our environment resulting from urbanization and industrialization. In response to public dissatisfaction with those conditions, various levels of government have taken actions aimed at defining the extent of existing environmental damage, halting the spread of pollution, and maintaining or restoring the quality of the environment. In the area of water quality, these have often taken the form of legislation, or water quality criteria, with an accompanying requirement to check, or monitor, wastewaters for conformance.

Over a year ago, the Army recognized the need to plan for and allocate resources to provide water quality monitoring systems at our installations. In cooperation with the Army Corps of Engineers, this Agency has been asked to provide technical assistance in defining the essential elements of these systems for the purpose of specifying design criteria to enable construction and procurement of equipment. To date, our work has focused on Army Ammunition Plants due to the significant water quality problems encountered frequently at these installations. This paper summarizes the Army Environmental Hygiene Agency's approach to this complex problem.

THE US ARMY ENVIRONMENTAL HYGIENE AGENCY.

This Agency provides consulting services in the field of environmental control in support of the mission of the Army Surgeon General to advise commanders on health aspects associated with managing pollution abatement programs. We have performad studies to describe and quantify specific pollutants in industrial effluents for many years. As a consequence, the Agency is continuously evaluating and improving techniques associated with the measurement of water quality, and has acquired considerable experience in monitoring program development. This experience is directly applicable to the development of design criteria and the allocation of resources where relatively sophisticated monitoring of industrial effluents or receiving waters is required on some routine basis to satisfy varied objectives.

APPROACH TO PROGRAM DEVELOPMENT.

Let us examine the design of systems which will monitor wastewaters from a diverse group of installations, where effluents may vary individually in volume, concentration, and potential effect. We recognize that any monitoring program must also meet constraints of technical attainability, economic feasibility, and flexibility in the sense that it should meet not only present needs, but also be capable of revision to incorporate technological change or to meet information requirements established in the future.

In recommending monitoring programs for Army munitions manufacturing facilities, the Agency addresses these constraints through a basic monitoring program capable of revision to meet future needs or to incorporate technological advancement.

A BASIC PROGRAM.

This program, which is developed during a field visit, consists of specific recommendations in the following areas.

Locations for monitoring stations on the major industrial and domestic effluent streams and in the receiving waters are recommended. Appropriate direct reading instrumentation, often coupled with an alarming system based upon a general indicator parameter, and suitable sample collection apparatus are specified for these stations. Recommendations are also made concerning the location and type of hydraulic structures or other apparatus to permit flow measurement.

A sample collection and analytical schedule is formulated which identifies those parameters known or anticipated to be of interest, and which permits the development of valid data concerning concentration of specific pollutants in the effluents and receiving streams associated with the installation.

Finally, recommendations are made concerning the effort required in support of the program. Attention is given to provision of utilities at individual monitoring stations, suitable analytical techniques, the required laboratory facilities and equipment, and the manpower at various skill levels required to accomplish sample collection, analysis, and maintenance of supporting equipment.

PROGRAM EXPANSION.

The basic program may be readily revised or expanded through additional, improved direct reading instrumentation, the development of a more sophisticated alarming system based upon specific ions, and the use of

automated equipment in the processing and evaluation of data and in the preparation of routine reports. Ultimately such a monitoring program may be incorporated into a process control network to provide for process optimization, or initiate remedial measures in the event of an emergency situation.

THE MONITORING CONSULTATION.

The activities in the development of such monitoring programs fall into three categories; the coordination, field work, and engineering evaluation phases.

During the coordination phase, appropriate objectives for the monitoring program are defined in conformance with the needs of the installation.

The field work phase is necessary to become completely familiar with the installation. This familiarity is necessary to recognize those factors in the process which will govern or constrain the selection of parameters and location of sample points.

During the evaluation phase, supporting materiel requirements are estimated, manpower requirements predicted, and the engineering report prepared.

COORDINATION

During the coordination phase, contact is established with those agencies or organizations whose activities, interests, or requirements will have some impact upon the scope or configuration of the monitoring program. An appropriate starting point is the major command responsible for the installation. Here, information is obtained concerning projected future levels of production, history of past problems associated

with operations, items of management emphasis or interest, funding constraints, and an overall appraisal of the priority assigned to work scheduled for the installation. Another primary point of coordination is the installation itself, since the monitoring program must be tailored to meet the needs of the user. Installation operating and supervisory personnel are the most competent sources of information on the processes and potential pollutants involved. The third point of contact is the district office of the Army Corps of Engineers. This office provides information on the scope, status, and impact of existing or proposed plant modification or modernization projects, to include facilities for water quality control. The construction lead time for a monitoring program may be at least two years. It is important to appreciate and plan for those changes in configuration or operating conditions at the installation which will occur during this construction time.

Other contacts of particular importance are the regional office of the US Environmental Protection Agency and the applicable state regulatory agency. These groups provide information on history of past problems, existing or anticipated stream or effluent standards, desired reporting requirements and information on anticipated trends or changes which may affect the objectives of the monitoring program.

Finally, it is good practice to establish contact with any special agency which may have an interest in the receiving streams or effluents associated with the facility. Examples of these agencies include the

Tennessee Valley Authority, the Delaware River Basin Commission, or any other interstate compact agency controlling the receiving waters; or any regional sewer authority which may receive domestic or industrial effluents from the installation.

Once these coordination activities have been completed, it is possible to define monitoring objectives which the program should be designed to satisfy.

FIELD WORK PHASE.

Activities during the field work phase include defining locations and equipment for monitoring stations, recommending parameters to be monitored and estimating sample collection frequency to ensure adequate data, and the detection of significant fluctuations in water quality. Factors involved in formulating these recommendations will now be discussed in greater detail.

MONITORING STATION LOCATION.

Factors considered in recommending locations of monitoring stations, and the associated instrumentation or equipment, include, for want of a better term, the coverage of the station; the relative ease of access to the proposed location; and other considerations which ensure that the data collected at the location is responsive to the needs of the user.

The coverage of a station implies that combination of topography, history, and destiny of the surrounding area which determine the volume and composition of the stream monitored. An appraisal of the terrain gives some measure of the areal extent of the drainage basin, and

determines the volume of natural runoff which may be anticipated. The drainage networks, both natural and sewered, are further topographical considerations which fix the location of monitoring stations. The potential pollutant sources within a drainage basin are particularly influential in determining the location of monitoring equipment. Finally, the destiny of a drainage area, as reflected by proposed modification development or modernization, may either establish or obviate the need for monitoring any given discharge.

Access to a proposed location is also a factor in the selection of monitoring locations. In addition to frequent visits for sample collection and routine maintenance of equipment, the requirement for utilities support and the need for physical security to prevent possible vandalism must be considered.

Other considerations in locating monitoring stations or equipment include any history of past problems or complaints involving a particular stream or effluent; any potential legal responsibility resulting from the identification of the stream as either an effluent or receiving water for the installation; and public concern over the quality of the effluent or stream. Such considerations may dictate the need for surveillance monitoring simply to document the absence of pollutants.

In summary, monitoring stations are located on effluent and receiving streams to permit either detection and surveillance of specific pollutants associated with manufacturing processes; to demonstrate the absence of pollution; or to document the impact of military operations on a receiving stream.

PARAMETER SELECTION.

In formulating the list of parameters to be measured, a new set of considerations, constraints and complicating factors become apparent. A logical approach, coupled with a working knowledge of the industrial processes involved, the general water quality of the receiving streams, and the program objectives, is imperative at this point in order to arrive at a manageable analytical workload in the final program.

The first consideration in selecting parameters to include in any monitoring program is the program objectives. For example, if one objective is to demonstrate compliance with water quality standards, the program must include those parameters for which measurable standards have been established. This generally leads to inclusion of a large number of specific parameters. If, on the other hand, the principal objective is to detect leaks or spills, a single indicator type parameter such as pH or conductivity may be appropriate.

The second, and perhaps most apparent, consideration in parameter selection is the nature of the plant industrial processes. Familiarity with the raw materials utilized, the waste materials associated with the manufacturing operation, the effectiveness of waste treatment facilities, the condition of the physical plant and the properties of the finished product, will give an indication of pollutants which may appear in the receiving or effluent streams. Examination of operating records generally leads to identification of several specific parameters as well as certain general, indicators of gross pollution.

A third consideration influencing the specification of parameters is expressed or potential public interest in the environmental impact of the military installation. Parameters identified through this consideration are usually those associated with, or influencing beneficial uses of waters in proximity to the installation. Both general water quality indicator parameters and specific chemical parameters associated with the manufacturing process may be dictated.

Constraints are imposed upon the selection of parameters by the availability of material resources, inherent limitations in the sampling procedures utilized and limitations inherent in analytical techniques applicable to industrial wastewaters.

Material constraints are largely self-explanatory. Money spent for expensive and elaborate monitoring of all conceivable parameters might better be directed toward more effective pollution abatement facilities, for example. The difficulty of obtaining a representative sample must be considered carefully when specifying parameters such as grease and oil or settleable solids, since these may not be uniformly distributed through the waste stream or may be lost in the sampling equipment. Sampling limitations are also apparent when substances are chemically or biologically degradable, mutually reactive, or highly volatile. Analytical limitations often force reliance upon general indicator parameters, such as total organic carbon in the case of complex organic compounds. For many substances, analytical methodology has not been specified or recognized by regulatory agencies; or the so-called "standard methodology" is not applicable to industrial wastewaters. Such cases are exemplified by the present lack of approved

specific methods for analysis of explosive decomposition products, and by the misleading results which may be obtained when industrial effluents are analyzed for biochemical oxygen demand.

WASTES IN MUNITIONS MANUFACTURE.

Parameter selection, and the specification of analytical methodology, is further complicated by the diversity and complexity of many industrial wastes. The attainment of program objectives is hindered by such considerations as the presence of interferring properties such as color or turbidity; by special sampling and handling procedures necessary to monitor substances such as grease, oil, and surfactants; the time required to analyze for parameters such as BOD, or kjeldahl nitrogen; and by requirements to monitor for substances which are inadequately defined or which may have an unknown impact on receiving waters, such as trace organics, biological inhibitors, or certain toxicants.

Although the preceding discussion emphasizes the complex nature of many industrial wastes arising from munitions manufacture, it is still possible to make some generalizations regarding these wastes. Indeed, the greatest source of variation in monitoring program content, from installation to installation, stems from regulatory requirements rather than from variation in waste characteristics encountered in the various plants. A brief discussion of the wastes associated with munitions production follows:

The various processes involved in munitions manufacture can be divided into four categories: explosive and propellent manufacturing;

metal parts or projectile fabrication; missile, bomb, and projectile loading; and maintenance, rehabilitation, or demilitarization operations. The industrial wastewaters associated with these operations also fall into four general categories.

The first of these includes the various forms of explosives, either finished, impure, or explosive which has undergone degradation and is no longer recognizable. A second category of wastes would be those related to the chemical manufacturing operations associated with explosives production. Examples of these are organic and inorganic acids, hydrocarbons, or solvents lost from purification processes. The group of wastes associated commonly with metal parts manufacturing includes grease and oil; spent pickling or plating solutions, characterized by either extremes of pH or high toxicity; and those waters associated with metal plating and paint stripping operations, characterized by high suspended solids, high dissolved solids, aromatic organic compounds, and extremes of pH. The final category of wastes associated with munitions production are those from supporting operations. Examples of these are boiler and cooling tower blowdowns, backwash from water treatment or ion exchange processes, and effluents from domestic sewage treatment plants and laundries.

Recognization of similarities in the wastes encountered simplifies the work of identifying pollutants of interest. Such similarities support a concept of a generalized monitoring program which may be tailored to fit requirements of individual installations. Indead, if more uniform standards are adopted throughout the country, it is to be hoped that some standardization of monitoring equipment may be realized.

SPECIFICATION OF COLLECTION FREQUENCY.

A third major activity is the estimation of sampling frequency. This assumes particular importance since it has a direct bearing upon the statistical validity of the data and a great influence on the cost of operating the program. Four collection alternatives are available, each of which has advantages and disadvantages which determine its applicability to any situation.

The first is that of continuous measurement. This offers advantages where surveillance is of importance, and is generally limited to indicator parameters where it is imperative that instantaneous peaks are discerned and recorded. This method generally involves the highest cost for equipment and maintenance. The large volumes of data generated may defy meaningful interpretation.

The second alternative involves a sample composed of a series of increments collected on either a time basis or in accordance with variations in flow. This is referred to as time or flow proportioned composite sampling, respectively. While a serious disadvantage of composite sampling is that peaks of pollutant concentration are attenuated, it remains one of the more attractive methods. The most obvious advantage is that the resulting sample is analogous to the total flow or discharge during the surveillance period. Put more simply, composite sampling offers a compromise between the high cost of continuous surveillance, and the pitfalls of assuming that a discharge is constant in composition and can be represented by a single sample.

The third and fourth collection alternatives involve grab sampling in accordance with either a randomized or deliberate schedule. These methods offer advantages where low cost is of importance; where measurement of an instantaneous, predictable peak is desired, as in the case of a batch discharge; or where the flow to be measured is of relatively steady and constant composition, in which case a sample collected at random may be assumed to be representative of the discharge. Grab sampling equipment may be actuated automatically or collection may be done manually. The principal disadvantage of these methods lies in the fact that there is absolutely no sensitivity to variation in quality, and the assumption is made that the sample is indeed representative of the total flow.

Factors which dictate the selection of one alternative method over another, and determine the frequency with which samples are taken, are the objectives of the overall monitoring program; the industrial processes involved at the installation; and those constraints arising from cost, materiel limitations, and available technology. Program objectives which demand the observation of peaks, or require the detection of leaks and spills often imply continuous measurement or composite sampling; while cost and technological constraints dictate that such parameters as BOD or grease and oil be evaluated on a grab sampling basis. High maintenance costs, poor reliability and the presence of interferring or masking substances often render the use of continuous measurement through specific ion probes or on-line analytical equipment impractical.

The experience and knowledge of plant operating personnel, together with guidance from regulatory agencies, are invaluable to the engineer in determining and specifying sample collection techniques and frequencies.

ENGINEERING EVALUATION PHASE.

During the engineering evaluation phase the capability and adequacy of existing analytical facilities at the installation are evaluated to estimate supporting materiel and the personnel required to conduct the monitoring program as recommended.

Based upon extensive experience in conducting intensive, temporary on-site monitoring programs, Agency personnel are competent to estimate personnel and equipment requirements for sample collection, sample preparation, laboratory analysis and analytical quality control.

Due to differences in the servicing requirements and performance of different models of instrumentation, it is considered impractical at this time to estimate manpower requirements for routine calibration and maintenance of monitoring equipment. Likewise, without complete knowledge of available data handling equipment and the internal procedures to be employed for interpretation and review, the time required for data manipulation cannot be estimated. Although not directly addressed, in the final report, the need for these manpower and materiel commitments is recognized and pointed out to the using installation.

Estimates of materiel for the monitoring program include on-site measuring and direct reading instrumentation, sample collection and

preservation equipment, hydraulic structures and flow measurement or totalizing apparatus, and the necessary instrumentation and laboratory equipment required for analytical chemical support and calibration. Adequate allowances are made to provide maintenance floats for certain major items of equipment. Required laboratory equipment is recommended for each parameter to be analyzed, based upon the numbers of analyses to be performed.

Where manpower estimates are made, appropriate skill levels are identified. For example, a higher degree of technical proficiency and training is expected of the analytical chemist than that required for sample preparation. This task, in turn, requires a higher skill level than that of sample collection.

Finally, a formal engineering report is prepared which embodies a recommended monitoring program satisfying the present and foreseeable future needs of the installation. Identification and description of the monitoring stations and their associated equipment, schedules of sample collection and analysis, recommendations concerning chemical analytical methodology and necessary supporting equipment; and estimates of the required manpower to accomplish this program are included in the form of design criteria. The engineering report includes a summary of pertinent federal and state regulations applicable to effluents and receiving streams associated with the installation. In most cases, the proposed program has been informally coordinated with both federal and state regulatory agencies prior to publication.

While the program is a recommendation, it has been recognized by regulatory agencies as conforming to present and foreseeable future requirements.

Through the wastewater monitoring consultation, the US Army Environmental Hygiene Agency is currently providing a service to Army munitions manufacturing installations by developing and recommending comprehensive, flexible, and attainable water quality monitoring programs. These programs are responsive to immediate requirements and needs; capable of future revision to incorporate changing technology or monitoring objectives, and will yield direct management benefits to the user, enabling the installation to demonstrate compliance with existing and foreseeable regulatory requirements, detect spills or harmful discharges from the installation, record quality trends and fluctuations in both effluent and receiving streams, and furnish accurate information to management, upon which decisions may be based.

FRAGMENTATION HAZARD EVALUATIONS AND EXPERIMENTAL VERIFICATION

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INTRODUCTION

During the last three years, the Department of Defense Explosive Safety Board has conducted a number of studies whose objective has been to ultimately characterize the fragment hazard, from accidental munition explosions, to unprotected personnel. The major result of these endeavers has been the development of a computational model. (Ref. 1) The model determines the probability of injury or damage by fragments from a single munition round to a variety of targets including a person standing in the open. In order to determine these probabilities the model predicts the number density in the ground plane of all fragments. These fragments are then screened as to being hazardous to selected targets using a criteria of critical mass and velocity.

The model specifically treats the fragment hazard associated with a single munition and has been utilized to generate single unit fragment hazard data for seven common military munitions. While single unit detonation does not represent a realistically severe accident situation, previous work indicates that multiple unit (i.e., stacks) fragment hazards may be proportional to single unit results. In support of this hypothesis, the computer model has generated results which compare favorably with experimental results; involving stacks of 750 lb bombs, obtained in the NWC-China Lake tests of March 1970. (Ref. 2).

The results generated by the computer model are dependent upon, and quite sensitive to, the munition effectiveness data which are input. These data were originally generated to support munition effectiveness studies and are the result of explosive tests of single unit munitions. This is the only known source of information concerning near field estimates of munition fragment size, number and initial velocity. However, since it has been collected to be utilized in weapon effectiveness studies, it is

primarily concerned with the fragments which are effective within the applicable range of the munition. This has normally led to a set of data which has a high degree of resolution, in terms of weight intervals, where the greatest number of fragments are concentrated. This unfortunately is at a rather low fragment weight (e.g., below 300 grains). The remaining fragment weight of the munition is quite substantial, but because it does not break down into very many fragments and is not always projected into the designed zones of munition effectiveness, its recorded resolution is usually quite poor.

Another inadequacy of recorded munition effectiveness data is concerned with its use in representing the basis for multiple unit munitions fragment hazard analysis. Here, the primary concern is whether the munition fragment size, number and initial velocities will be similar for munitions in single and multiple units. As noted previously, results coming out of previous detonation tests of stacked munitiuns indicate that thin wall "bomb type" munitions tend to fragment into similar size fragments for both multiple and single units. However, qualitative appraisal of similar results for thickwall "shell type" munitions indicated marked dissimilarities between multiple and single unit munitions.

This paper is concerned with presenting the results of the single munition hazard data, its favorable scaled comparison with experimental bomb data, its favorable comparison with experimental shell data and a detailed examination and comparison of two "shell type" stacked munition tests. (Ref. 3)

MUNITION HAZARD EVALUATIONS

A set of computations has been made for seven single unit munitions. The results are presented as contour maps of total fragment number densities, damaging fragment number densities and injury probability as a function of radial distance from the munition source within a constant sector of the ground plane. (i.e., the nose, base, and side sectors). These results are presented in Table 1 and serve both to demonstrate the capability of the computer algorithm and also as design aids for explosive safety personnel.

TABLE 1

SUMMARY TABLE FOR THREE PRINCIPAL DIRECTIONS AT 1 HIT PER 600 SQ FT (ENTRIES ARE IN RADIAL FEET)

Munition	All Fragments			Hazardous Fragments **		
	Nose	Side	Tail	Nose	Side	Tail
750 (1)*	440	1060	740	220	690	500
500 (1)	220	825	595	210	670	450
175 (1)	250	840	575	250	450	200
155 (1)	290	810	510	120	400	230
105 (0)	240	650	360	100	270	150
8 (1)	325	660	240	140	520	120
5 (1)	310	720	340	140	275	150

*(0) = Unaltered Data

(1) = Altered Data

**Hazardous fragments are defined as having in excess of 58 ft lbs kinetic energy

The table gives the computed distances corresponding to a fragment density of one hit in 600 sqft for all fragments and fragments with a terminal energy in excess of 58 ft lbs.

COMPARISON OF SCALED SINGLE UNIT ANALYTIC AND MULTIPLE UNIT TEST RESULTS

Previous effort (Ref. 1) has indicated that analytic results, obtained utilizing a computer model, compare favorably with experimental results involving stacks of 750 lb bombs obtained in the NWC-China Lake tests of March 1970. These results are illustrated in Figure 1. Here analytic results were generated for a single unit 750 lb bomb, multiplied by three and compared to multiple unit bomb stacks in 2 x 3 and 5 x 3 configurations. Thus, in this case, a simple multiple of the single unit result compared quite favorably with the multiple unit case.

Figure 2 (Ref. 2) provides a similar comparison of results between Yuma test results and analytic results obtained for a single unit 155-mm projectile. The single unit munition result, in this case, has been multiplied by a factor of 10 corresponding to there being 10 shells oriented in a similar direction to the single shell (i.e., with the longitudinal axis of the shell perpendicular to the side sector). At ranges of interest (i.e., beyond 1000 ft), agreement between analytic and experimental results is again quite good. This is especially true considering that the munition effectiveness data, used in generating the analytic result, will be shown to be quite different than the actual distribution of fragment sizes picked up at Yuma.

Similar comparisons with Eskimo I results are not, as yet, possible since changes must be made in the computer model to allow for initial shell orientations which correspond to the Eskimo I stack configuration (i.e., shells stacked nose up).

GRADING AND ANALYSIS OF YUMA TEST FRAGMENTS

To minimize the effort required in weighing and counting over 2 tons of Yuma fragments, a first task was directed toward establishing a minimum weight fragment. This task also involved an estimate of the amount of material above and below the chosen minimum weight.

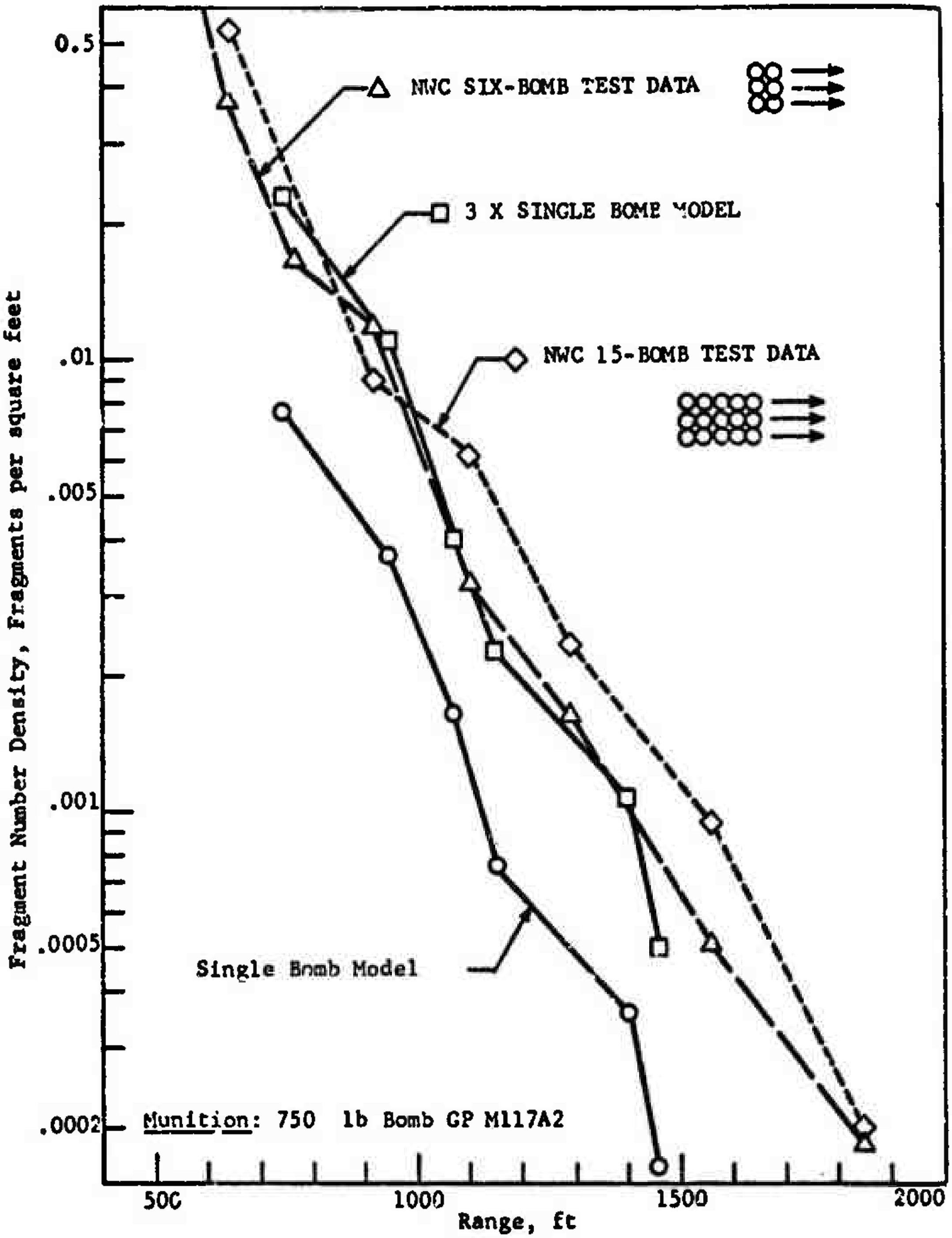

Figure 1 COMPARATIVE SIDE-SPRAY FRAGMENT DATA FOR ALL FRAGMENTS - 750 lb BOMBS

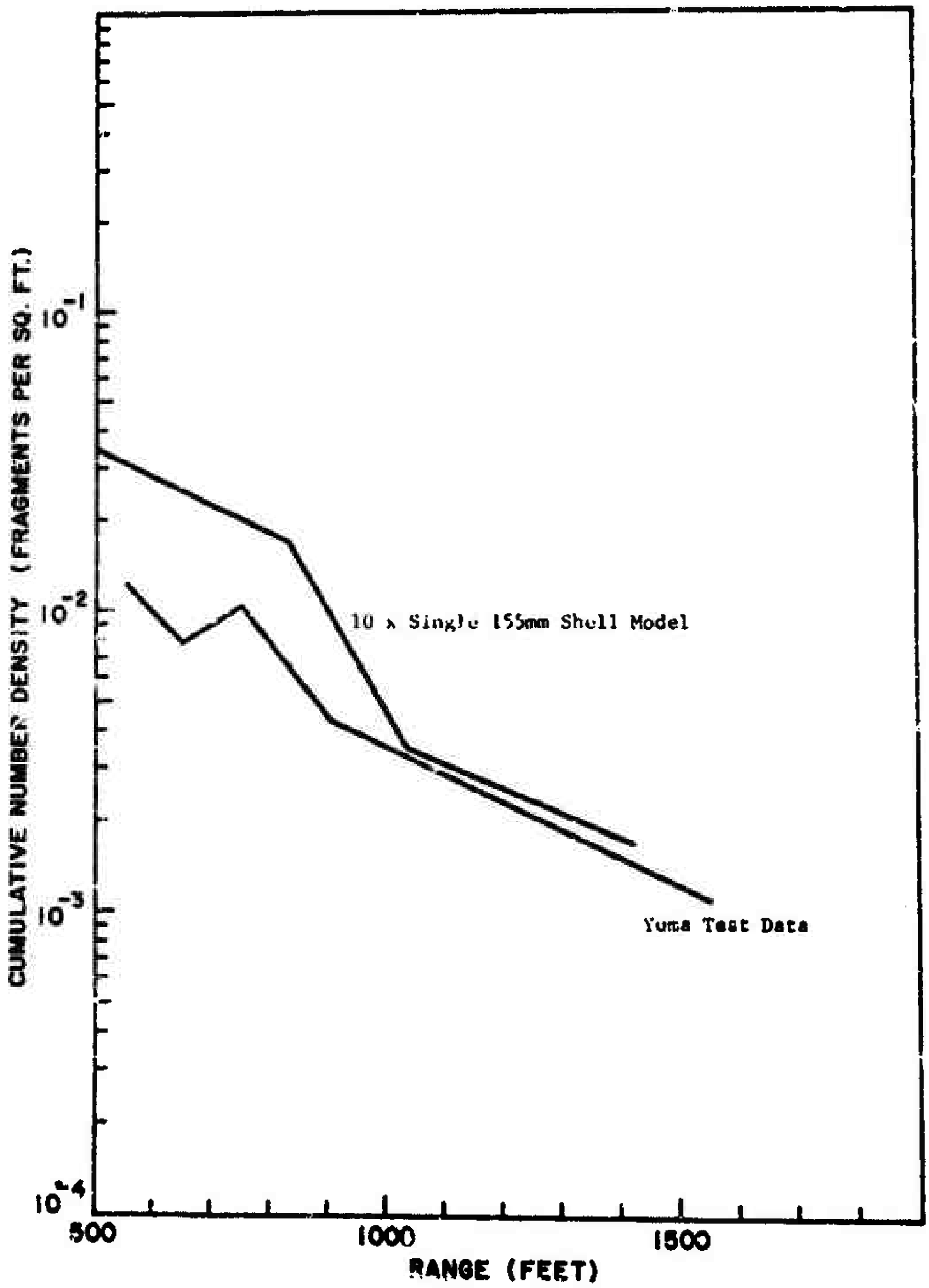

Figure 2 COMPARATIVE SIDE-SPRAY FRAGMENT DATA FOR ALL FRAGMENTS - 155mm SHELLS

Based on study objectives to characterize the fragment hazard at Yuma, and to then compare this hazard to the Eskimo I hazard, expedience dictates that detailed weighing and counting of fragments be directed at only those fragments which result in a hazard to unprotected personnel.

The criteria for hazardous fragments to unprotected personnel have been established as:

- A hazardous fragment has a kinetic energy of 58 ft-lbs or greater, and
- An acceptable density of hazardous fragments is not more than one per 600 sq ft

Utilizing the first of these criteria together with previously developed analytic relationships (Refs. 4, 5), it is possible to establish a minimum fragment weight of interest.

Figure 3 depicts the relation between two energy criteria; terminal velocity and fragment weight for fragments in free fall (i.e., upper register fragments). Figures 4 and 5 depict a similar relationship for lower register fragments and show the fragment weight-range necessary to exceed the given energy criteria (i.e., 11 or 58 ft-lbs). In each figure there is a separate curve corresponding to a particular initial fragment velocity.

Documentation of the Yuma test results (Ref. 6) indicates that fragments had an initial velocity of about 5000 ft/sec. Current quantity-distance tables indicate an 1100 ft required distance for 15,000 lbs explosive. Table 2 is a summary of the critical fragment size for the two criteria in both the upper and lower registers.

Based upon the weights shown in Table 1 the stored fragments were divided into three size categories: those remaining on a 1 in. sieve, those remaining on a 5/8 in. sieve, and the material passing through the 5/8 in. sieve. Table 3 is a correspondence between the sieve categories and approximate weight in grains.

Table 4 summarizes the weight distribution for all the material out to a 2000 ft range and for the material between 1000 and 2000 ft. This latter category is the primary zone of hazardous fragments.

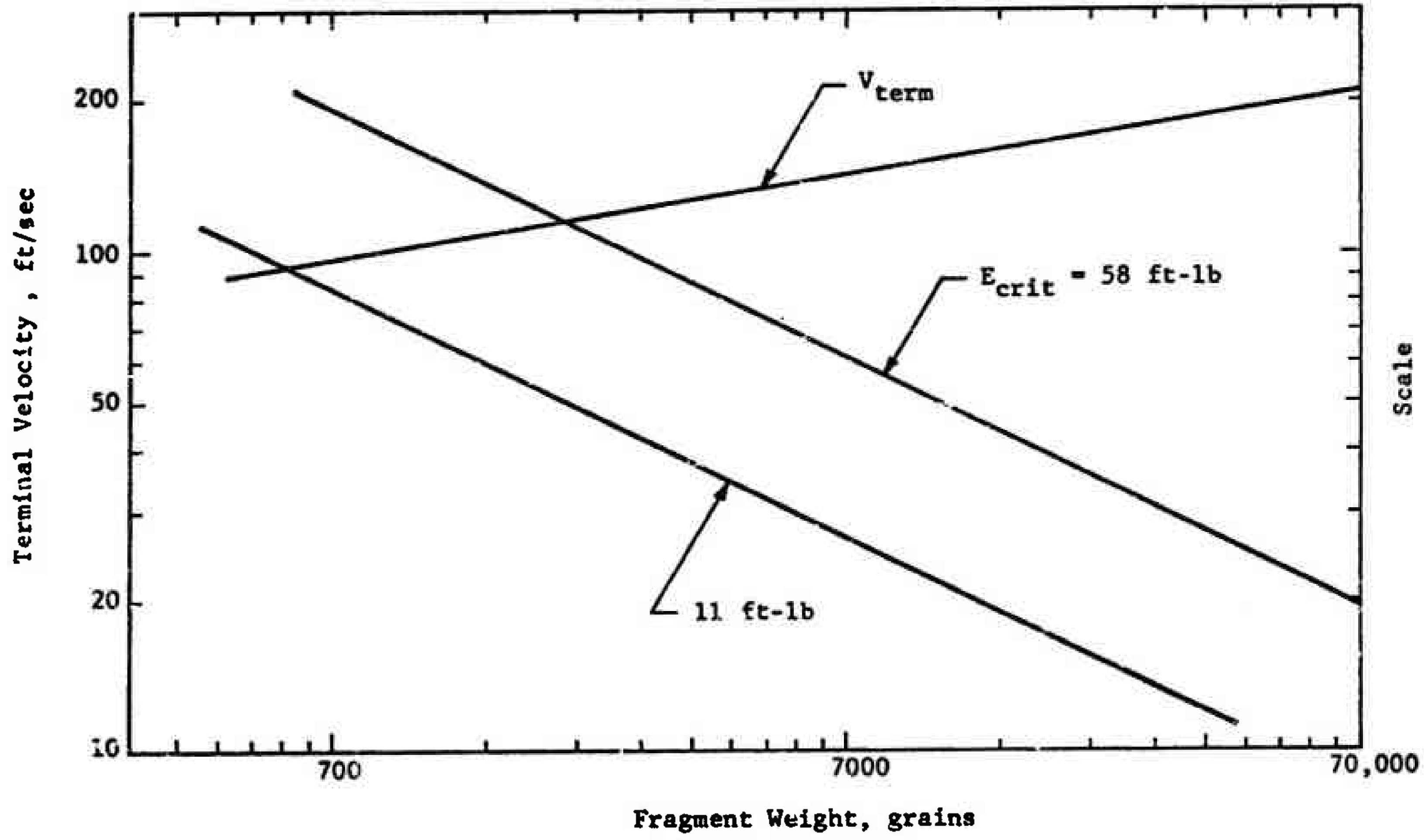

Figure 3 INJURY CRITERIA AND TERMINAL VELOCITIES FOR UPPER REGISTER FRAGMENTS

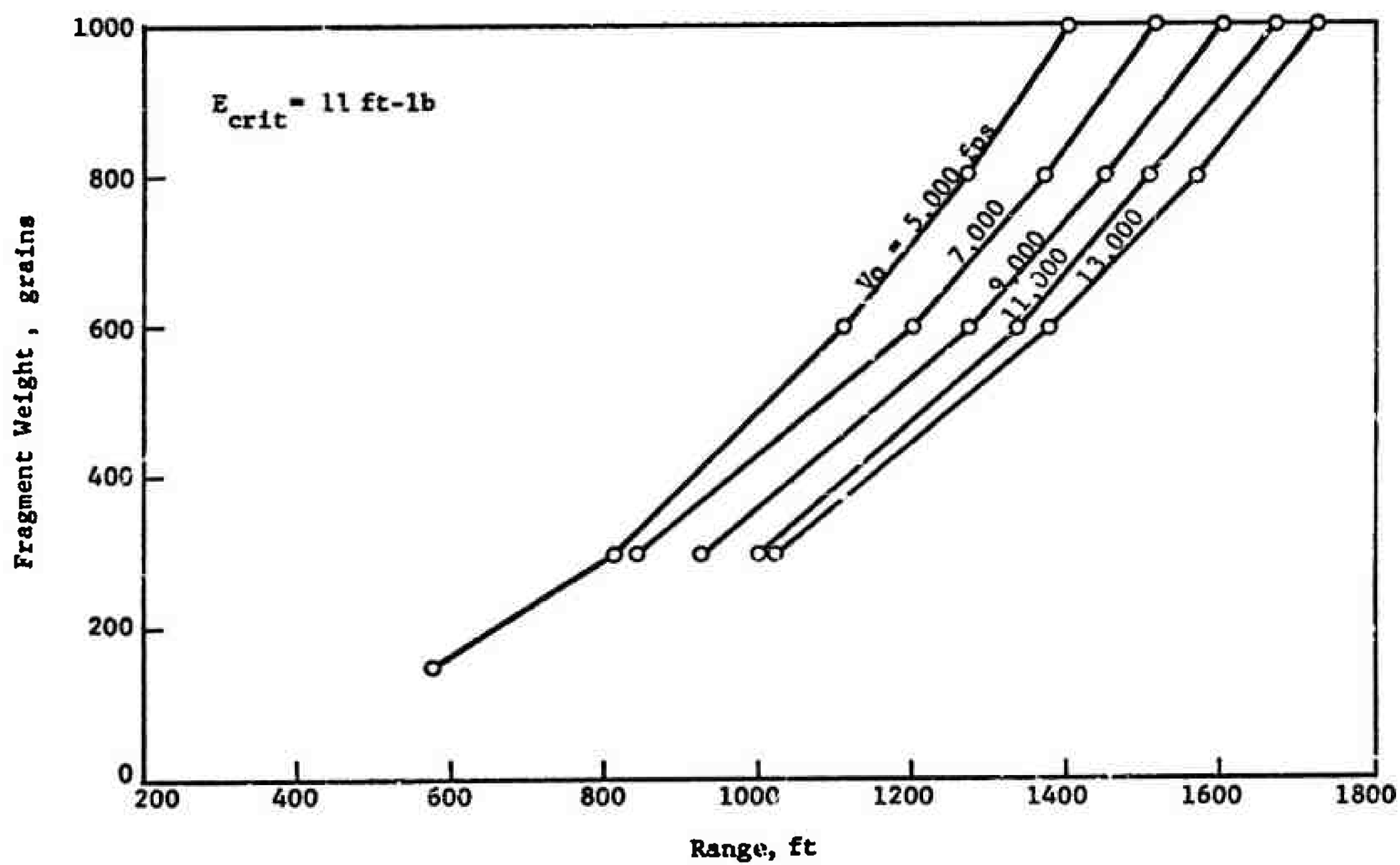

Figure 4 FRAGMENT WEIGHTS AND RANGES FOR LOWER REGISTER FRAGMENTS WITH A CRITICAL ENERGY OF 11 FT-LB

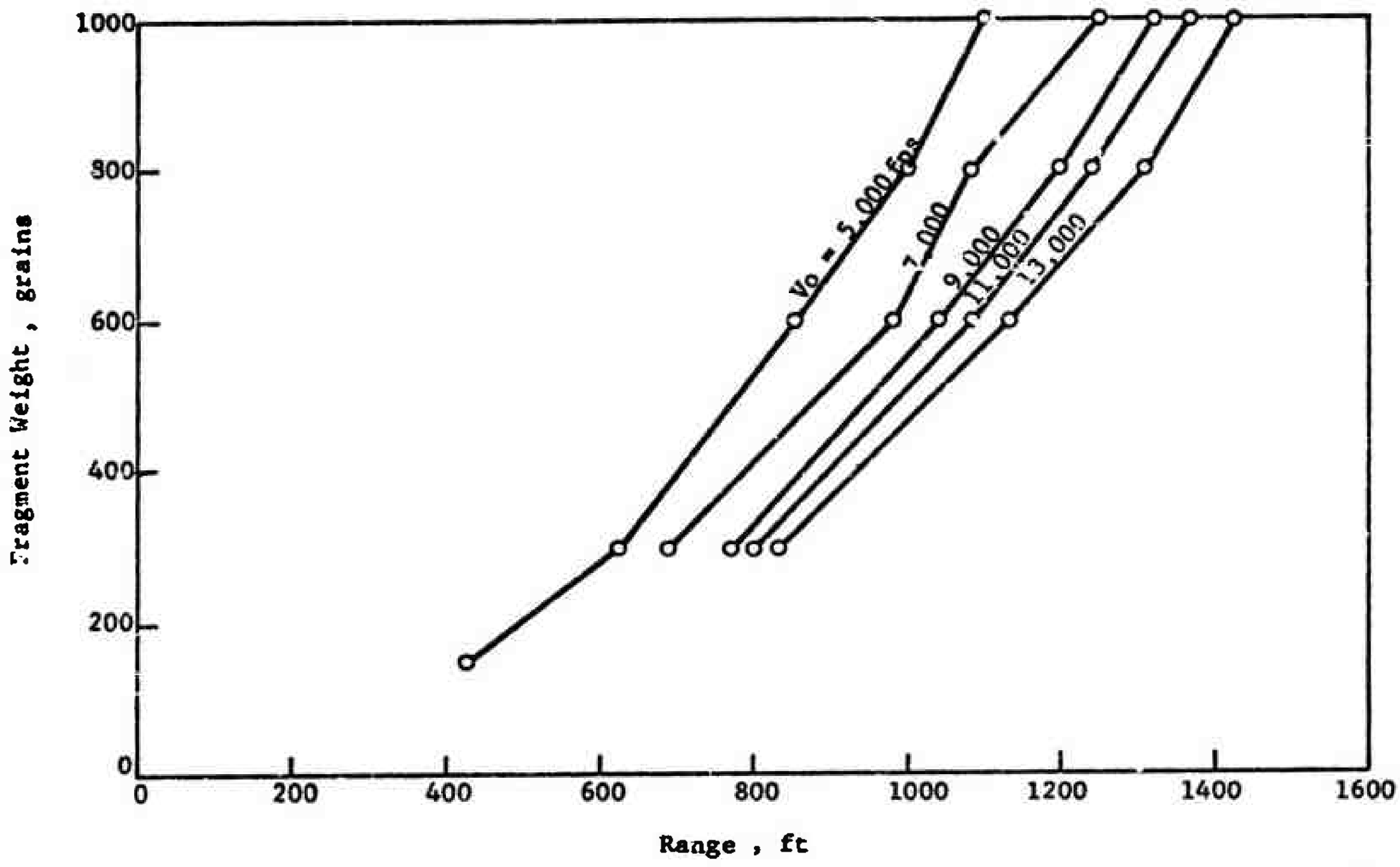

Figure 5 FRAGMENT WEIGHTS AND RANGES FOR LOWER REGISTER FRAGMENTS WITH A CRITICAL ENERGY OF 58 FT-LB

TABLE 2

CRITICAL FRAGMENT WEIGHT (grains)

	Energy Criteria	
	58 ft-lbs	11 ft-lbs
Lower Register	1000	590
Upper Register	1960	574

TABLE 3

SIEVE SIZE - FRAGMENT WEIGHT CORRESPONDENCE

Sieve Size (in.)	Average Fragment wt (grains)
1	over 1000
5/8	over 400
< 5/8	less than 400

TABLE 4

SUMMARY OF TOTAL WEIGHT DISTRIBUTION

Ground Range	0-2000 ft		1000-2000 ft	
Sieve Size (in.)	Fragment wt (lbs)	Percent	Fragment wt (lbs)	Percent
1	1840	42.1	1118	57.3
5/8	1027	23.5	600	30.8
< 5/8	1504	34.4	232	11.9

The above results indicate a twofold justification for disregarding fragments passing through the 5/8 in. sieve. That is, they are well below the critical weight required of hazardous fragments and they represent less than 12 percent of the total material in the major area of concern.

If these small fragments are disregarded, the effort required to weigh and count the remaining fragments is reduced such that this can be done on an individual fragment basis. This is desirable since it will not be possible to characterize the fragment hazard, associated with the Yuma test, with maximum resolution.

A load cell mechanically coupled to a weighing pan was used to weigh the fragments. The load on the cell was directly proportional to the weight of the fragment. The output voltage of the cell was directly proportional to the load. This voltage is recorded on paper tape and, through a linear relationship, was converted to the weight. Figure 6 is a system diagram for the weighing-counting device.

The first step in analyzing the fragments collected at Yuma was to screen out those fragments falling through a 5/8 in. sieve. This left 18,655 potentially hazardous fragments having a total weight of 19,299,759 grains. Thus, the mean weight of those fragments were 1,035 grains; well above the mean weight of published munition effectiveness data.

Figure 7 depicts the cumulative weight distributions for (1) single 155-mm projectile as reported in munition effectiveness data, (2) all fragments collected in the Yuma 1000 unit experiment and (3) the potentially hazardous fragments collected at Yuma. This figure gives the percentage of total fragments falling below a given weight. It is obvious from this illustration that the fragments emanating from the Yuma experiment are considerably heavier than those reported for the case of a single unit munition detonation. For example, 50 percent of fragments fall below 320 grains for the single unit, below 650 grains for the entire set of Yuma fragments and below 2,050 grains for the set of Yuma fragments retained by a 5/8 in. sieve.

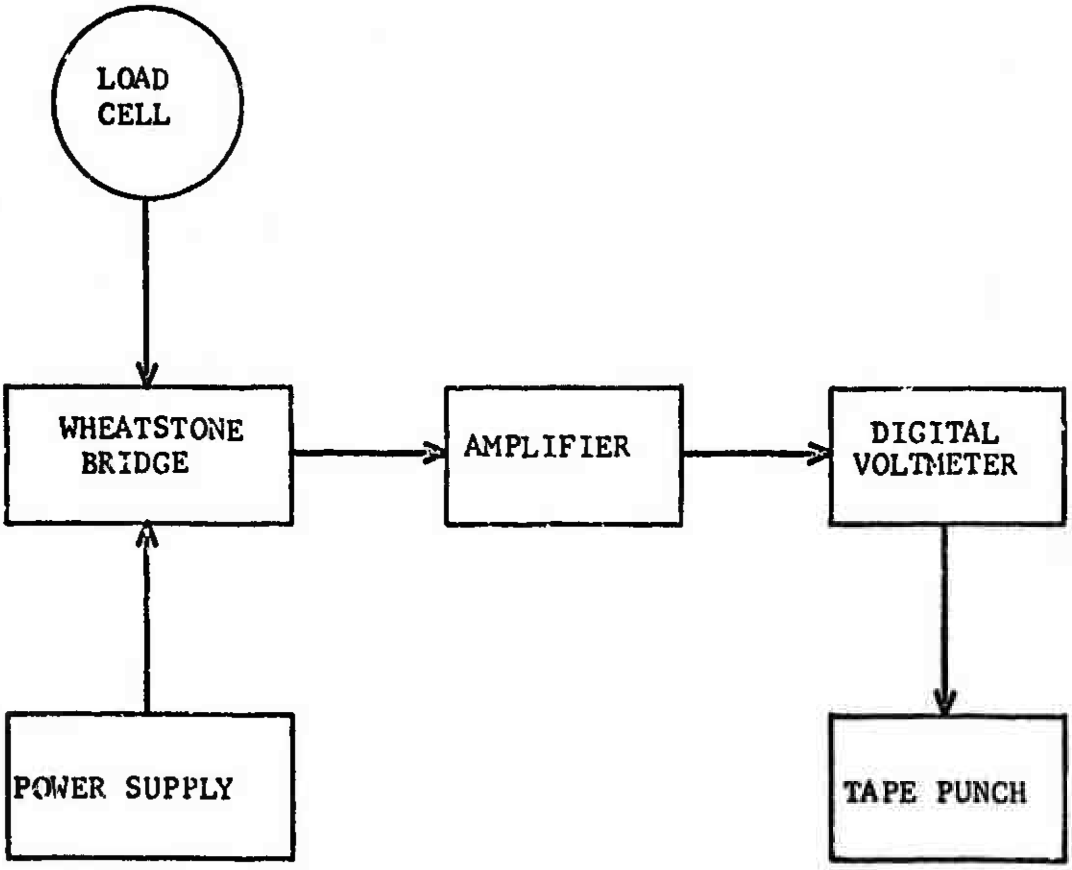

Figure 6 SYSTEM DIAGRAM

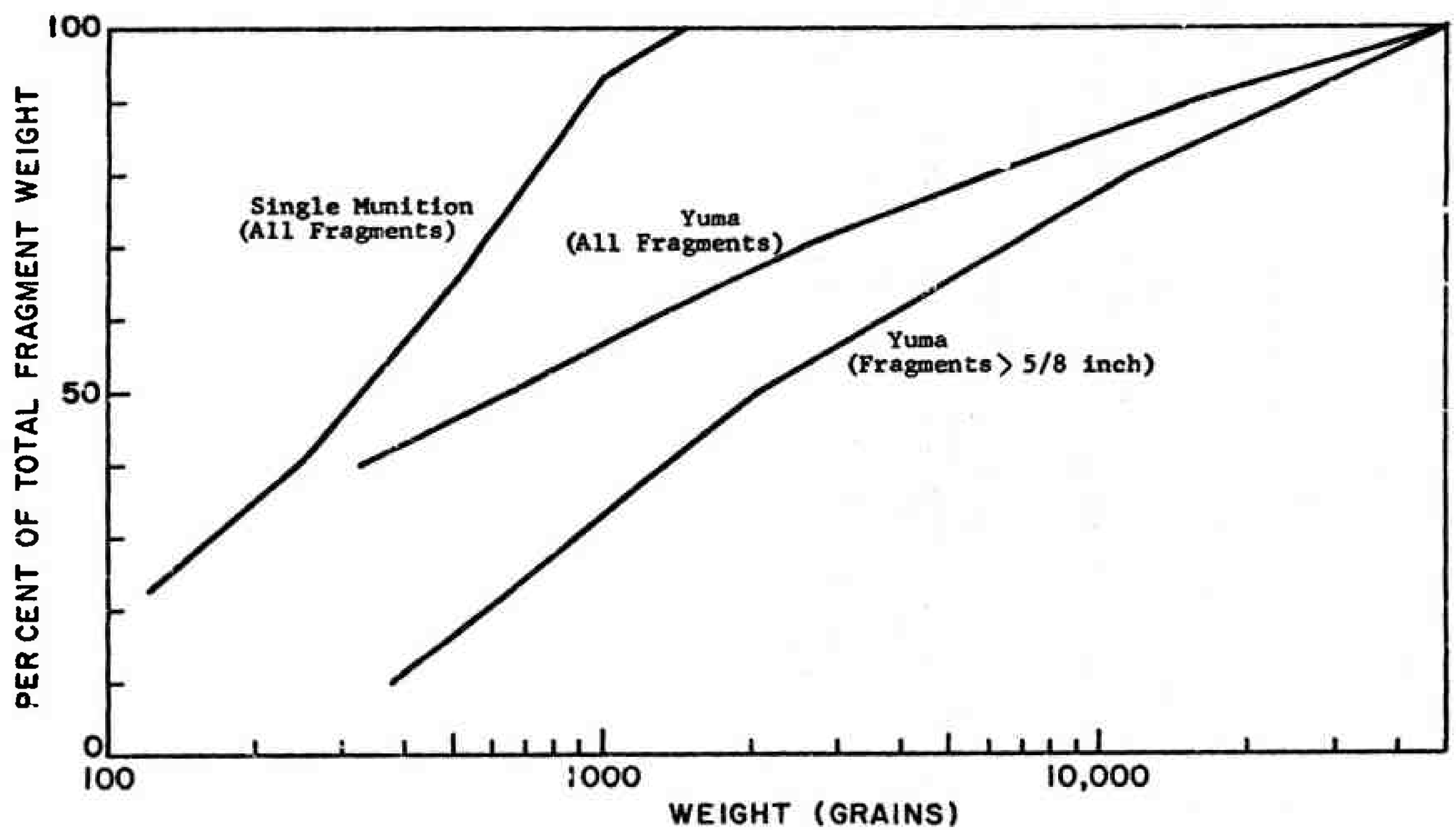

Figure 7 CUMULATIVE WEIGHT DISTRIBUTIONS

In addition to the cumulative weight distributions described above, cumulative number density as a function of fragment weight has been compiled for all collected fragments, broken down by rays and then by sectors within rays. Also, the cumulative number density as a function of range, for all fragments remaining on the 5/8 inch sieve, has been prepared. This last relationship has been developed separately for those fragments exceeding 11 and 58 ft-lbs and upper and lower register contributions distinguished. (Ref. 3). Results obtained from NWL, China Lake, California have been placed in a similar format to the Yuma results in order to compare the two tests.

SUMMARY

Based upon the test results and their subsequent comparison with analytic results, one may conclude:

- Fragments failing to stay on a 5/8 in. sieve will not be hazardous to personnel at ranges of interest.
- Fragments can be counted, weighed, and recorded for subsequent machine processing at the rate of about 100 fragments per hour per man-machine utilizing the equipment developed in this study.
- Fragments emanating from multiple unit stacks of shells are considerably larger in size than those coming out of a single unit detonation.
- The density of Yuma fragments was greatest in the base ray, was less in the nose ray and was least in the side ray.
- The density of Yuma fragments showed a considerable falloff at about 1300 ft from the point of detonation which coincides with the point where upper register fragments begin to be more hazardous than lower register fragments.
- The effect of target size and its dependence upon fragment terminal elevation angle are responsible for a less rapid falloff of the probability of serious injury at ranges beyond 1300 ft from the Yuma test detonation point.
- While there is some similarity of fragment size distribution from individual magnet-truck pickup runs, there is also sufficient variability between runs to preclude anything but complete pickup within a sector.

- The fragment densities collected at the NWC-Eskimo I test were greater for all weight regimes than their counterpart fragment densities collected at Yuma.

- The number of fragments per sq ft falls off at about the same rate, with increasing weight fragments, for both the Eskimo I and Yuma tests.

- The Eskimo I results showed a dropoff of fragment density with increasing distance from detonation for all rays, while the Yuma test results showed a build-up in fragment density followed by a similar dropoff as in Eskimo I for the nose and base rays. The side ray of Yuma showed a similar dropoff in density with increasing distance from detonation. This might have been due to shielding of lower register fragments, at NWC, provided by adjacent acceptor igloos and the earth barricade in the north ray.

- There was a similar falloff of fragment density with range for both the Yuma and Eskimo I tests. This took place at about 1100 ft in the Eskimo I test and about 1300 ft in the Yuma test and the rate of fall-off beyond these distances was about the same.

- There was, as in the case of 750 lb bombs, close comparison between Yuma and analytic results which were generated based upon munition effectiveness data and a simple multiple of the single unit result.

From these conclusions the following recommendations are made:

(1) Future far-field fragment data should be processed, in total, counting and weighing all fragments which remain on a 5/8 in. sieve at ranges beyond 1000 ft. For closer range fragments, an analysis similar to the one made in section one of this study should be made to determine the minimum fragment size of interest. In addition, new pickup techniques other than the use of a magnet truck should be given consideration. Such a technique might include the random placement of 100 x 100 ft patches of wire screening material throughout the far-field (i.e., random over the entire test area and not just covering specific rays). Such a procedure would allow for rapid deployment of collection zones and the screening material could also serve as a container for the collected fragments.

(2) As a result of the many similarities between the Yuma and Eskimo I tests, in terms of similar hazards for two quite different multiple unit stack configurations, and the close comparison of Yuma results with computer generated results, a testing program should be initiated to develop empirical scaling relationships between analytically derived results for a single unit munition and an approximation of the hazard due to an arbitrary multiple unit configuration of the same munition. Such scaling relationships should consider stack configuration parameters and the detonation characteristics of the stack.

(3) Another testing program should be initiated aimed at characterizing the near-field distribution of fragments (i.e., munition effectiveness data) emanating from multiple unit sources since this is the input required by the computer model to compute the far-field hazard. Again, such a testing program should consider detonation characteristics as well as stack configuration.

(4) Minor changes should be made on the computer model so as to obtain the ability of generating results for a munition source whose longitudinal axis is oriented at an arbitrary angle with the ground. Presently, only an angle of zero is considered and munitions stacked on end cannot be considered.

(5) Finally, an interim technique for determining the fragment hazard of multiple-unit stacks should be developed. Based upon the similar results obtained in the Yuma and Eskimo I tests, there seems to be a characteristic distance at which hazardous fragment density begins to fall off rapidly regardless of stack configuration or the number of units in the stack. If this is so, then a conservative approach might be to adopt this distance adjusted by some factor of safety.

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PRESSURES, FRAGMENTS, AND DAMAGE FROM BURSTING PRESSURE TANKS

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At the Explosives Safety Seminar last year, Mr. Petes from our Laboratory presented a paper titled, "Watch Your Equivalent Weight". The gist of what he said was that in most cases, it makes little sense to talk about the damage potential of rupturing pressure vessels in terms of an equivalent weight of TNT. The physics of an explosion and of a tank rupture are not the same. His talk was based on some preliminary calculations to obtain shock pressures from tank ruptures. The data I present today will further illustrate his point, although this is not my primary aim.

Simple calculations based on the isentropic expansion of the fill gas to ambient pressure yield the pressure-vessel rupture energy. Such calculations do not yield blast and fragment parameters. Yet, realistic hazard estimates depend on believable blast and fragment data. Even sophisticated calculations should be proven against experimental data. In this paper, I'll present the results of an experimental program that will add to the data base for pressure vessel rupture. The work I'm reporting was done for the Safety Office of the NASA Kennedy Space Center.

Before we begin, NASA (Ref. (1)) defines a pressure vessel as one containing a fluid whose expansion energy equals or exceeds that in 0.01 pounds of TNT. I'll use the word tank interchangeably with pressure vessel.

Now then, my paper deals with an experiment in which we inflated 5 tanks with N_2 until they burst. We measured blast and fragment parameters. The results of this program are reported in reference (2).

FIGURE 1

Here I show you the tank properties that are significant to our experiment. All tanks were made of titanium, 6 aluminum, 4 vanadium alloy. The skin thickness of tanks A and B was about 0.02 inches. Tank C was 0.1 inches thick and tanks D and E were about 0.368 inches thick. The burst pressures shown here are two to three times the working pressures.

The lower pressure tanks were pressurized directly from the N_2 bottles. A high pressure pump was used to pressurize the 8,000 psi tanks. The pump exhausted through a water-cooled heat exchanger. Tank E was cycled 55 times before it was elevated to rupture pressure. A cycle consisted of elevating the pressure to 5,000 psi, holding for 15 seconds, and then bleeding down to 4,000 psi.

Our blast measuring system was conventional. We used piezoelectric gages and an oscilloscope recording system.

FIGURE 2

Here you see an overhead view of the setup. The gages are in three strings radiating at intervals from the tank. The tank was set at the center of the square concrete firing pad. We also show photographic stations and a photographic screen.

Now, we'll get directly to our pressure measurements. Although we made some face-on pressure measurements, my comment will deal only with the side-on measurements.

FIGURE 3

I now show you some pressure histories from the closest positions to tank B. The traces begin at zero time. About 1.5 milliseconds later, the shock arrives at the gage and you see a discontinuous rise followed by a more or less smooth decay. In some cases there are double peaks near the shock front. These records are more or less typical of those from all tanks; and to some extent, to those from TNT explosions involving fragments.

FIGURE 4

In this figure, I show you the raw data from tank B. Recall that tank B was a cylindrical tank with hemispherical ends. As you see, the distance in feet is on the abscissa and the pressure in psi is on the ordinate. For our comparison the TNT curve, the solid line is based on the isentropic expansion of the fill gas to ambient pressure where TNT energy was taken as 1000 calories/gram. The dashed line is from a machine calculation using a one dimensional code called Wundy. In the calculation, the effect of the mass of the tank and the fill gas was not considered. The tank shell was considered to act like a shock tube diaphragm that disappears at tank rupture. The x's are actual scaled TNT measurements. The differences in tank rupture pressures are typical of all tank measurements in that measured data show a lack of symmetry about ground zero and, of course, pressures are depressed near ground zero.

FIGURE OFF

Now, we'll group the data in an effort to generalize, keeping in mind the variation in data along each blast line.

Recall that tanks C, D, and E were spherical tanks. Tank C had a diameter of 9.2 inches, Tanks D and E 27 inches. All three burst at about 8,000 psi.

FIGURE 5

In this figure, we averaged the pressures along all three lines for each tank and plotted them as a function of tank radius. I then fitted a curve to the data, the solid black line. This curve should be general for similar tanks burst at 8,000 psi.

I have also plotted as the dashed line a TNT curve, The TNT weight is based on the isentropic expansion energy of the chosen volume of N_2 where again TNT energy is considered to be 1000 calories/gram. From these curves, one can compute tank-rupture equivalent weight based on TNT.

FIGURE 6

Here, you can see that I have done just that. Based on peak shockwave overpressure, tank rupture equivalent weight is less than TNT out to about 24 tank radii or about the 4.0 psi level.

FIGURE OFF

Comparing the blast data from the spherical tanks with that from a spherical TNT charge is at least geometrically correct. The comparison of the data from the cylindrical tanks with spherical charge data is open to question. Certainly the blast field generated by a spherical TNT charge would differ from that generated by a cylindrical charge of equal weight. The cylindrical charge blast field depends on the length-to-diameter ratio and the detonation scheme. In the case of tank rupture, there is no detonation wave, therefore, no basis for comparison with cylindrical charge data.

FIGURE 7

Since the L/D of the cylindrical tanks was small, about 2/1, and the tanks had hemispherical ends, we treated them as equivalent volume spheres In this figure, we have plotted the peak shock overpressure vs distance in equivalent spherical tank radii for the two cylindrical tanks. To some degree, we would expect the fitted

curve, the solid line, to be representative of the pressure data from similar tanks burst at 600 psi. Again we have plotted a curve for an equal energy TNT burst---the dashed line.

FIGURE 8

Here I have plotted a TNT based equivalence for tanks burst at 600 psi. Again we see the extreme variation with distance. The crossover point here occurs close to the tank, about 7 tank radii. For the 8,000 psi tanks, the crossover point was at about 24 tank radii.

It might be of interest to look at the values of positive impulse. Recall that the shockwave pressures were depressed below those for TNT near the tank. The positive shockwave durations, however, were longer in this area.

FIGURE 9

This circumstance provided a positive shockwave impulse-distance curve similar in slope to that for TNT. A single TNT equivalent for tank rupture data for the 8,000 psi tanks over the distance interval covered here is about 0.76.

FIGURE 10

A similar situation obtains for the 600 psi tanks. Here, however, the impulse-distance curve is higher than the equivalent TNT curve. Tank equivalent weight is about 1.78 times that for TNT.

FIGURE 10 OFF

I remind you again that the cylindrical tank data are being compared with spherical TNT data.

Now, I'd like to talk briefly about the fragments from the tanka. We tried to recover a large sample and to measure their early velocities. Fragment recovery was aided by a 40 ft diameter arena with 6" celotex walla. The walls were 8 ft high. First I'll talk about the number of fragments.

FIGURE 11

Here, you see the 36 fragmenta recovered from tank B. The grid lines are 2 inchea apart. I remind you that tank B was a thin-walled tank with a 600 pai burst pressure. Those fragments pictured here repreaent 73% of the tanka weight. All the heavy parts were recovered. Thoae fragments not recovered were therefore akin fragments. So, we can say that the 32 recovered fragments represent 56% of the tanka skin weight. If we aaaume a similar weight distribution for the unrecovered fragments, then the tank burst into about 57 skin fragments.

Oddly enough, we also recovered 36 fragments from tank A. However these made up 61% of the akin material and we estimate the number of akin fragmenta from tank A to be about 54.

FIGURE 12

I show you now the 24 fragments we recovered from tank E. (Fragment 25 is not included). Remember this was the 6 ft^3 tank with 3/8 inch walls. These 24 fragments make up 51% of the tank's weight. Based on this tank E burst into 48 fragments. A similar analysis of the tank D fragments indicate that this tank burat into about 47 fragments. Incidentally, the heaviest of these weighed over 12 pounds, the lightest about 1/5 of a pound.

SLIDE OFF

We used two methods to meaaure fragment velocity. The firat was a simple breakwire aystem. A wire wrapped around the tank produced a signal to start an electronic interval counter. A

second wire at unit distance from the tank perimeter was used to stop the counter.

A second technique involved a simple stroboscopic photosystem. Briefly, the system used two camera stations. Each station consisted of a camera and a single flash tube. The tube was flashed four times. The first flash occurred at tank rupture, and the succeeding flashes at appropriately spaced times. The two photosystems allowed us to obtain fragment position time information. Both the breakwire system and the pohtosystem, did not yield fragment velocity information for every tank. However one or the other always operated so that we obtained fragment velocities for each tank.

FIGURE 13

This rather confusing slide shows the results of our measurements. The breakwire system did not operate for Tank A. However we obtained fragment position-time information showing initial fragment velocities of just over 1,000 ft/sec, as you can read in the far right column.

For tank B both systems yielded fragment velocities. However the breakwire system yielded a velocity of about 1215 ft/sec. The strobe system, over a longer interval, gave velocities just under 1,000 ft second.

Tank C breakwire velocity was over 1,200 ft/sec; strobe velocity over the first three feet was about the same.

For tanks D and E, a condensation cloud at the fill gas-air interface obscured the strobe photos. Even so, the breakwire system yielded velocities of about 1400 ft/sec.

I'll conclude my remarks with some qualitative observations of damage. There is little need to talk about the fragments. The damage potential of heavy fragments, several pounds traveling at supersonic velocity is awesome. These fragments sheared off heavy 3" pipes, went through 6" of celotex backed by plywood broadside on,

and still traveled over 300 yards from ground zero.

The blast from the tanks was rather mild--pressures that would rupture eardrums--maybe cause other damage. More impressive, the blast seemed to do things that would not be expected from 10 pounds of TNT. Specifically, the blast from tank D drove the 4' x 4' x 1.5' reinforced concrete firing pad 4 inches into the ground. Tank E drove the pad another 5" into the ground. Both tanks caved in and collapsed the arena walls. The 8.2 lb charges neither caved in the walls nor displaced the pad nor did we expect it to.

The tanks generated side-on shock wave pressures and positive durations that were different than those from an equivalent TNT energy source, but they combined to give positive shockwave impulses similar to those for TNT. Nevertheless, the tank rupture blast, qualitatively at least, seemed more violent than for a comparable TNT explosion.

REFERENCES

(1) Ecord, A. "Apollo Experience Report - Pressure Vessels." NASA Technical Note TN D-6975, Manned Spacecraft Center, Houston, Texas, September 1972.

(2) Pittman, J., "Blast and Fragment Hazards From Bursting High Pressure Tanks", NOLTR 72-102, U. S. Naval Ordnance Laboratory, Silver Spring, Maryland, 17 May 1972.

Figure 1 **TANK DATA**

Tank Letter Designator	Vessel Type	Vessel Shape	Dimensions	Serial Number	Pressure Data		
					Operate	Burst (Design)	Burst (Actual)
A	Aerozine 50 Fuel Tank	Cylinder with Hemi-spherical ends	Length = 24 inches Diameter = 13 inches Volume = 1.34 $feet^3$ Weight = 8.5 pounds	100311010010	188 psig	460 psig	625 psig
B	Oxidizer Tank	Same as Tank A	Length = 29 inches Diameter = 13 inches Volume = 1.68 $feet^3$ Weight = 10.2 pounds	100311020016	138 psig	460 psig	600 psig
C	Helium Tank	Sphere	Diameter = 9.2 inches Volume = 0.235 $feet^3$ Weight = 6.3 pounds	10048ME 00057	4,150 psig	7,500 psig	8,000 psig
D	Helium Pressure Vessel	Sphere	Diameter = 27 inches Volume = 6 $feet^3$ Weight ≈ 171 pounds	00407ACB 0025	3,250 psig	8,000 psig	8,000 psig
E*	Helium Pressure Vessel	Sphere	Diameter = 27 inches Volume = 6 $feet^3$ Weight ≅ 170 pounds	00407ACB 0001	3,250 psig	8,000 psig	8,130 psig

* This vessel was pressure cycled prior to rupture

All tanks were made of the same material, titanium, 6 aluminum, 4 Vanadium alloy.

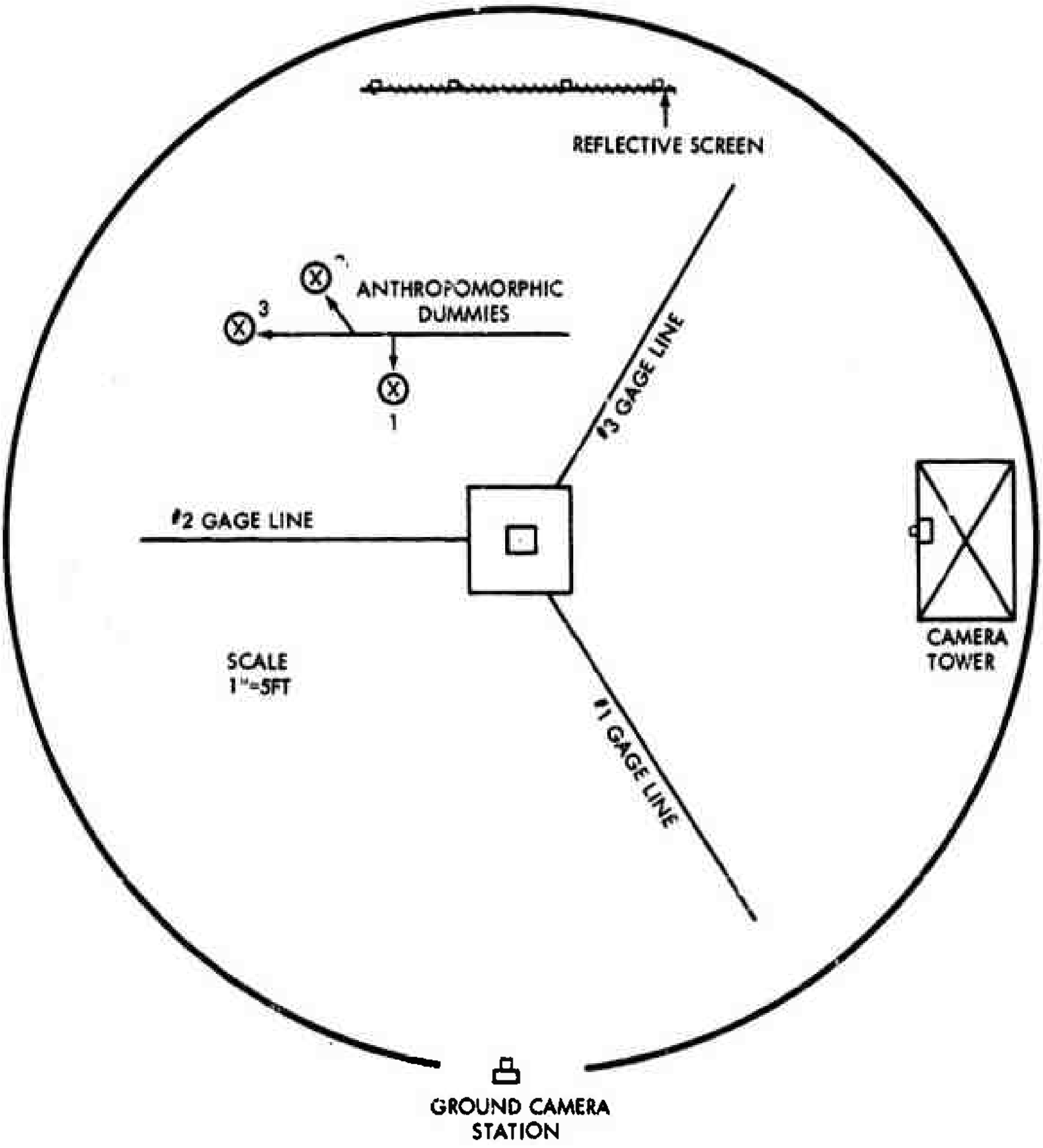
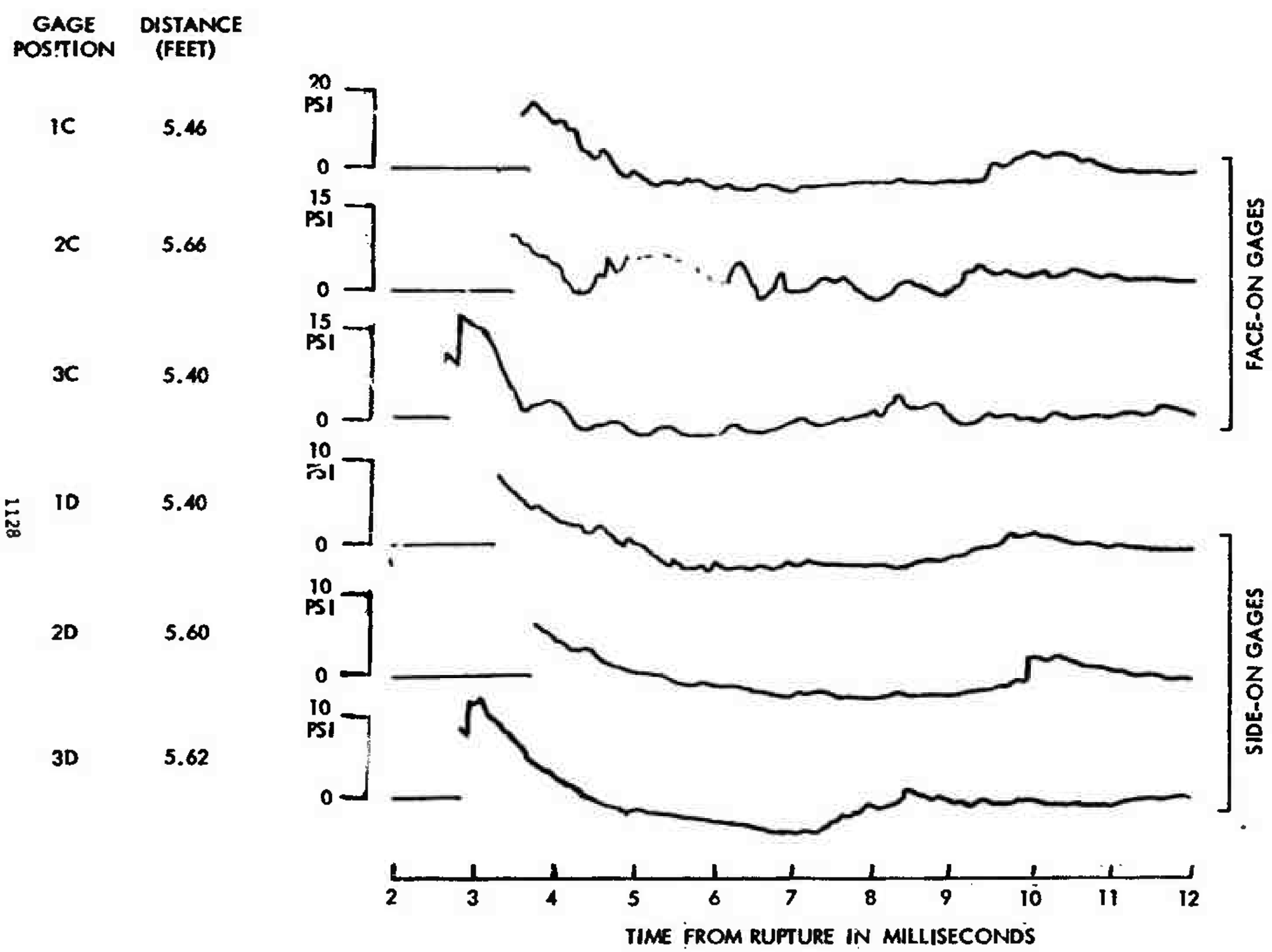


FIG.2 EXPERIMENTAL SETUP FOR TANKS A, B, C, AND D


GAGE POSITION
DISTANCE (FEET)
1C
5.46
2C
5.66
3C
5.40
1D
5.40
2D
5.60
3D
5.62
20 PSI
15 PSI
15 PSI
10 PSI
10 PSI
10 PSI
0
FACE-ON GAGES
SIDE-ON GAGES
2
3
4
5
6
7
8
9
10
11
12
TIME FROM RUPTURE IN MILLISECONDS
FIG. 3

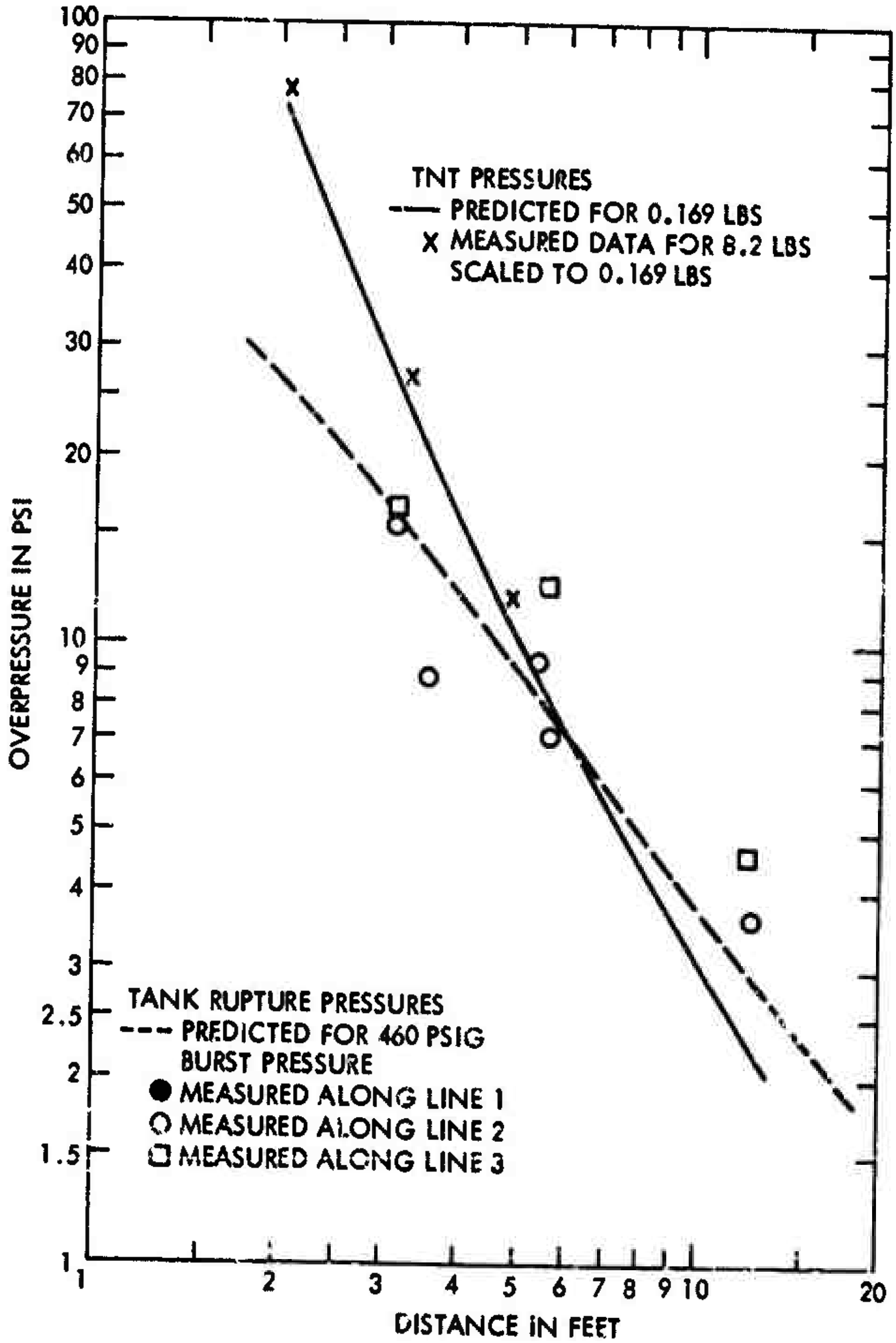


FIG. 4 SIDE-ON OVERPRESSURES FROM TANK B; 1.68 FT^3 TANK BURST AT 500 PSI

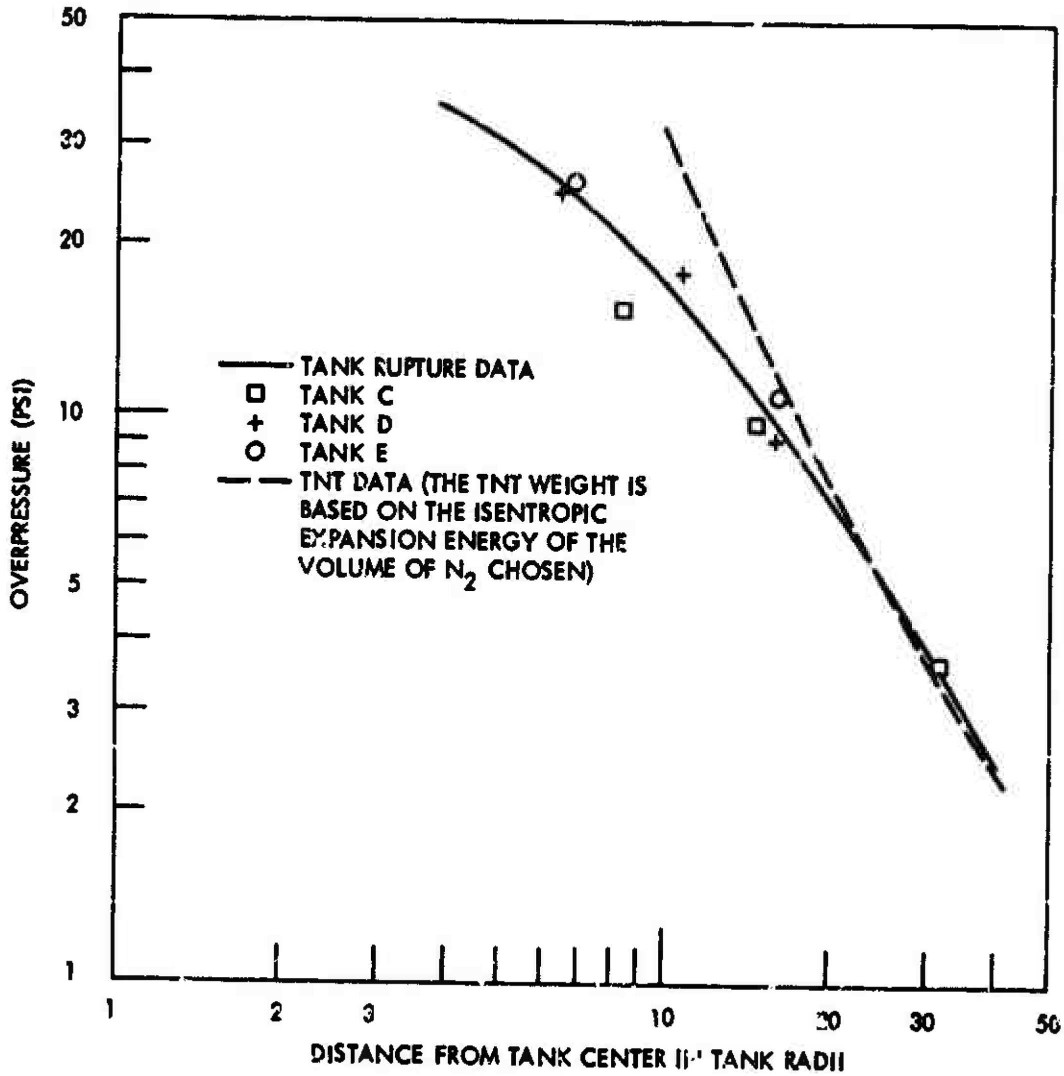


FIG. 5 PEAK AIRBLAST OVERPRESSURES FROM AN 8,000 PSIG TANK RUPTURE VS DISTANCE IN TANK RADII

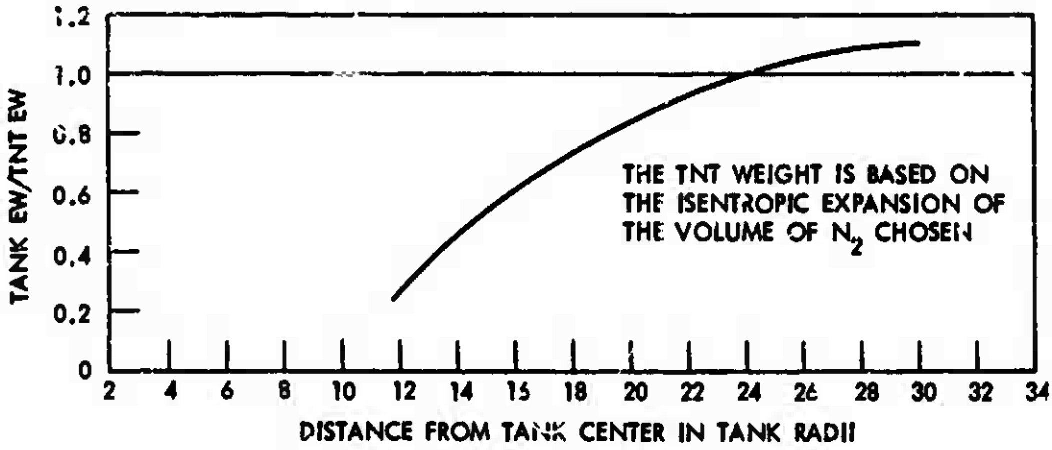


FIG. 6 TNT EQUIVALENCE OF THE AIR BLAST FROM AN 8,000 PSIG TANK RUPTURE BASED ON PEAK SHOCK OVERPRESSURE

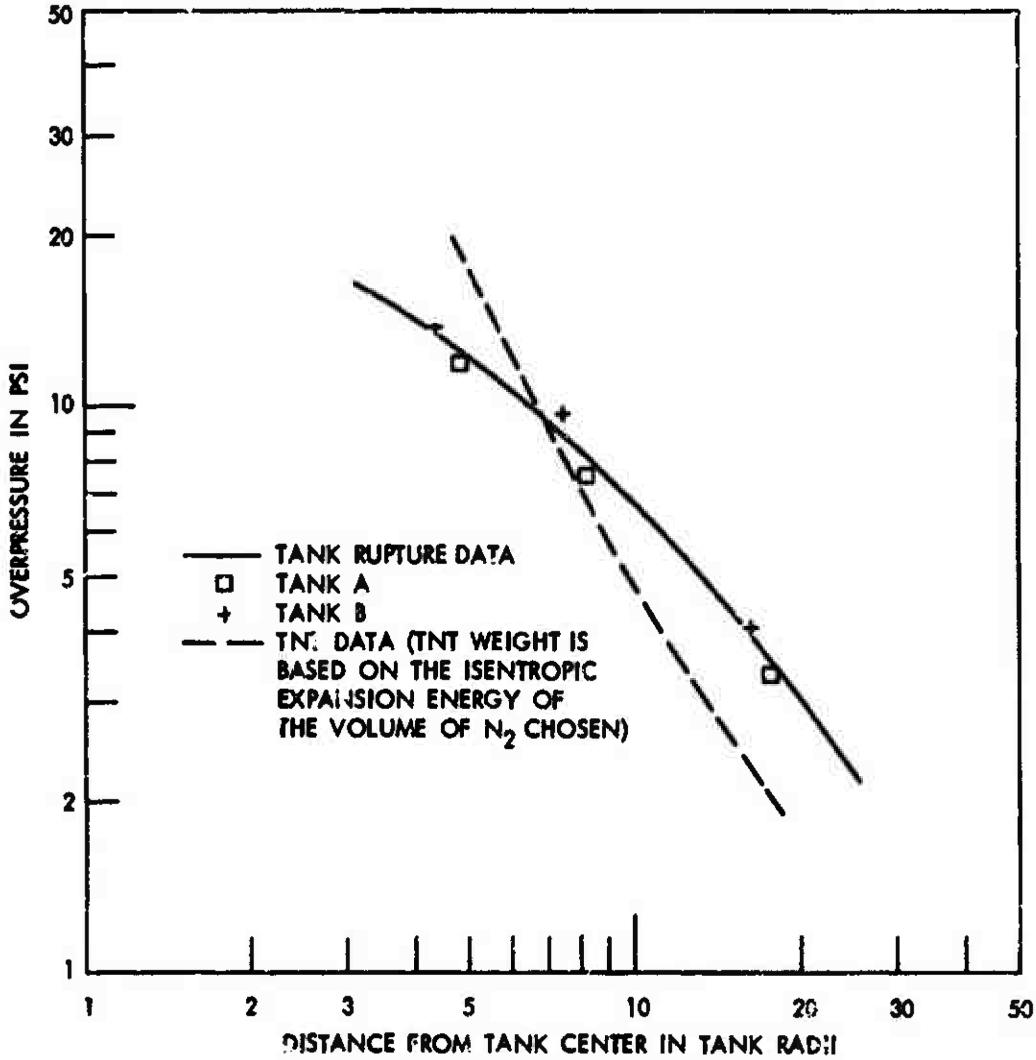


FIG. 7 PEAK AIRBLAST OVERPRESSURE FROM A 600 PSIG TANK RUPTURE VS DISTANCE IN TANK RADII

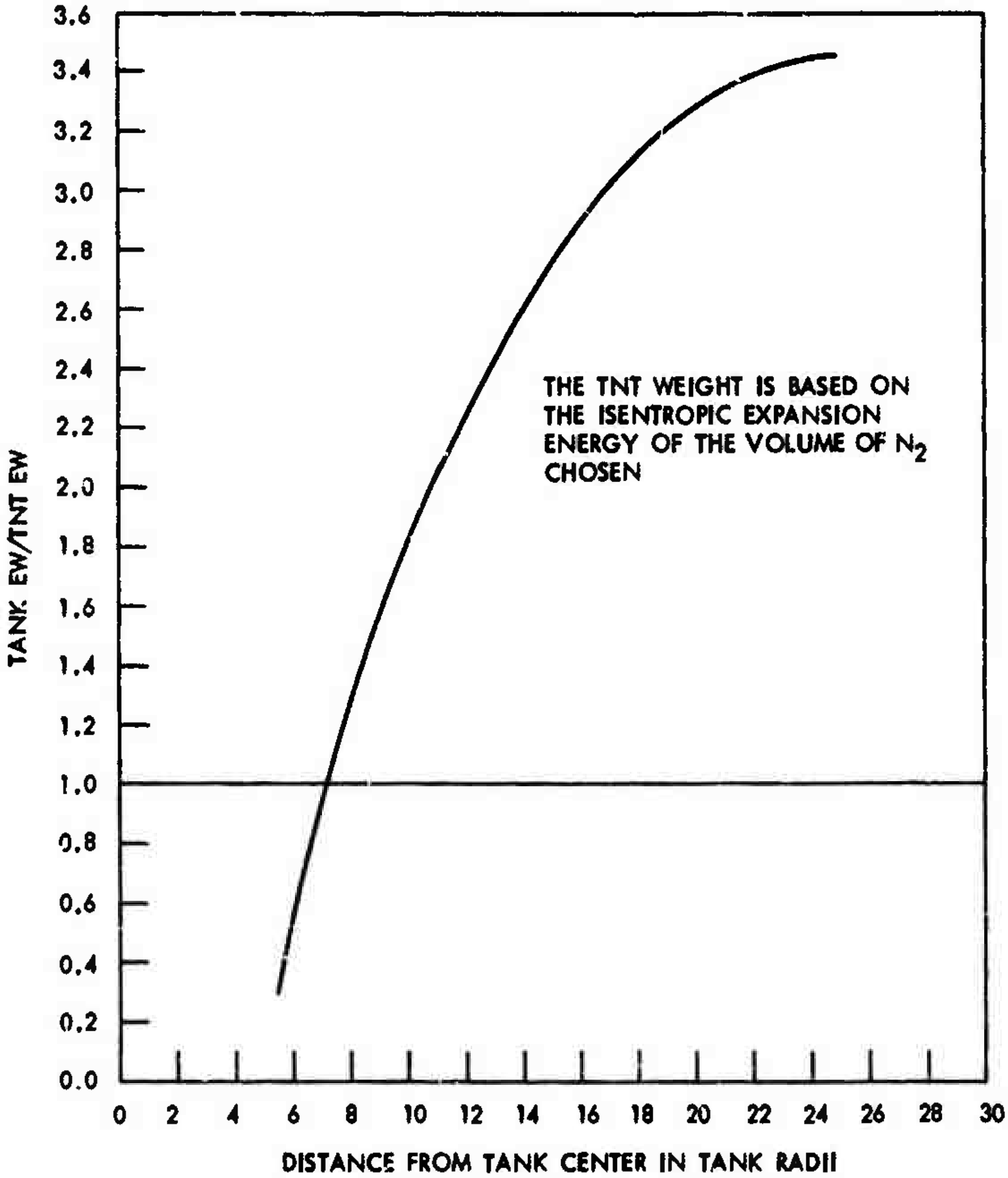


FIG. 8 TNT EQUIVALENCE OF THE AIRBLAST FROM A 600 PSIG TANK RUPTURE BASED ON PEAK SHOCK OVERPRESSURE

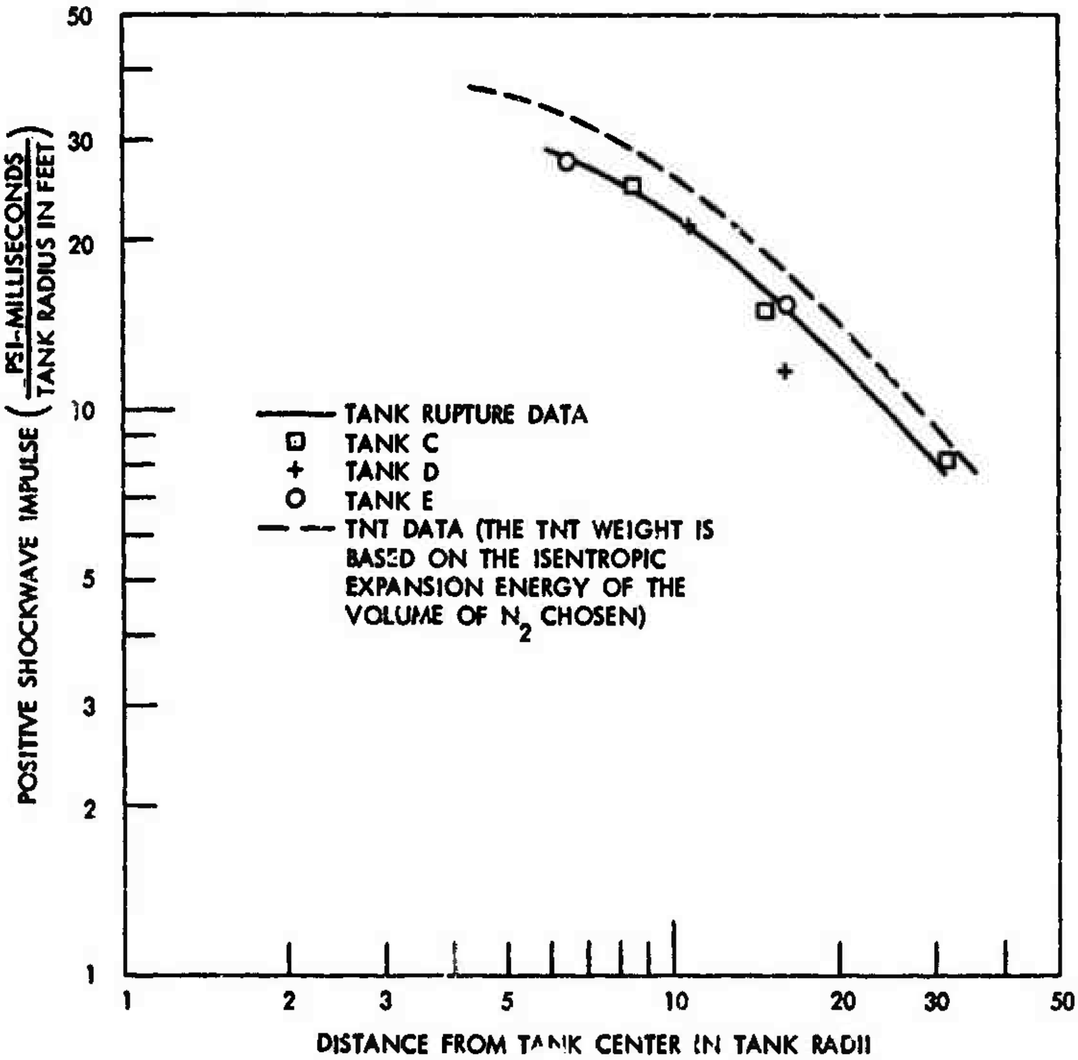


FIG. 9 POSITIVE SHOCKWAVE IMPULSE FROM AN 8,000 PSIG TANK RUPTURE VS DISTANCE IN TANK RADII

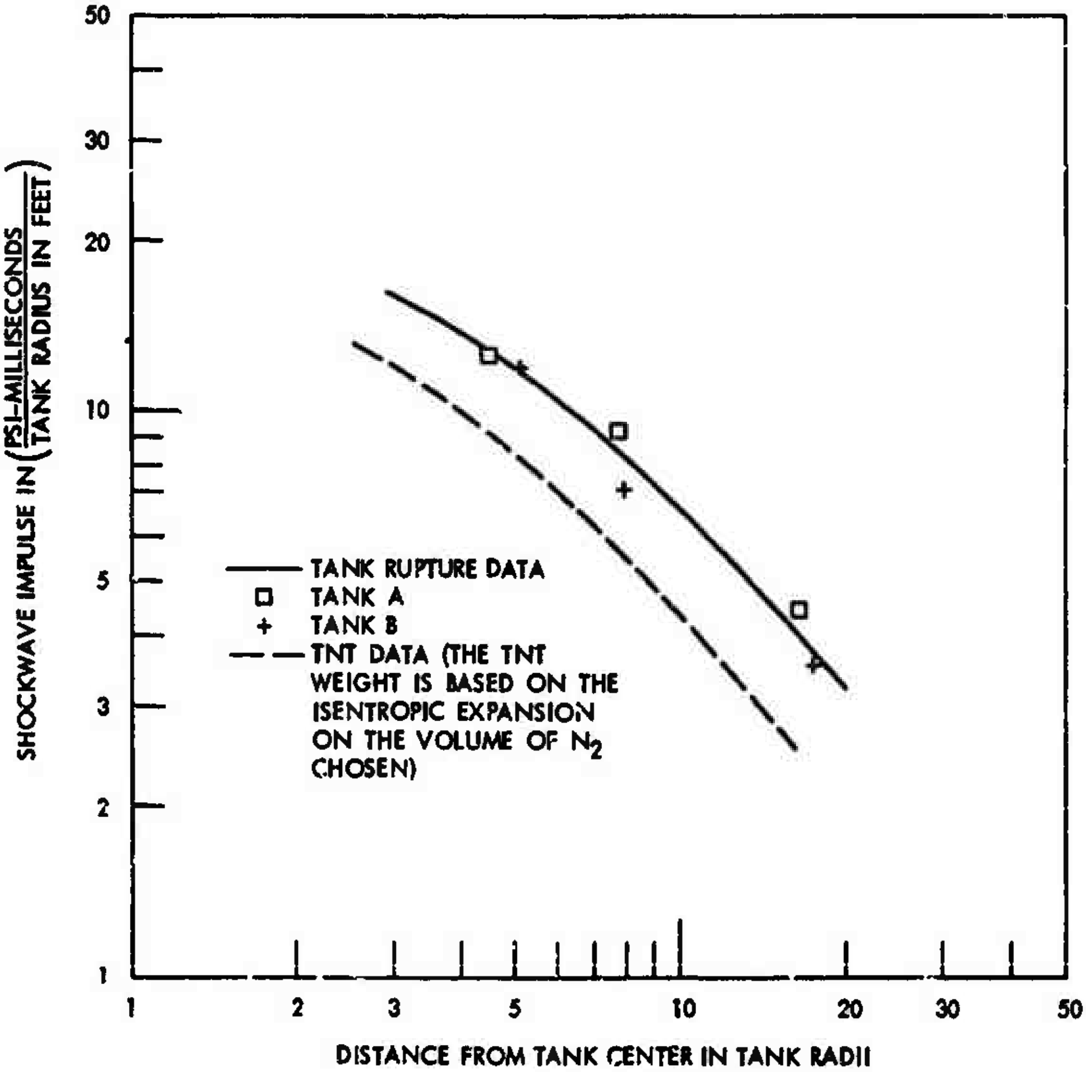


FIG. 10 POSITIVE SHOCK WAVE IMPULSE FROM A 600 PSIG TANK RUPTURE VS DISTANCE IN TANK RADII

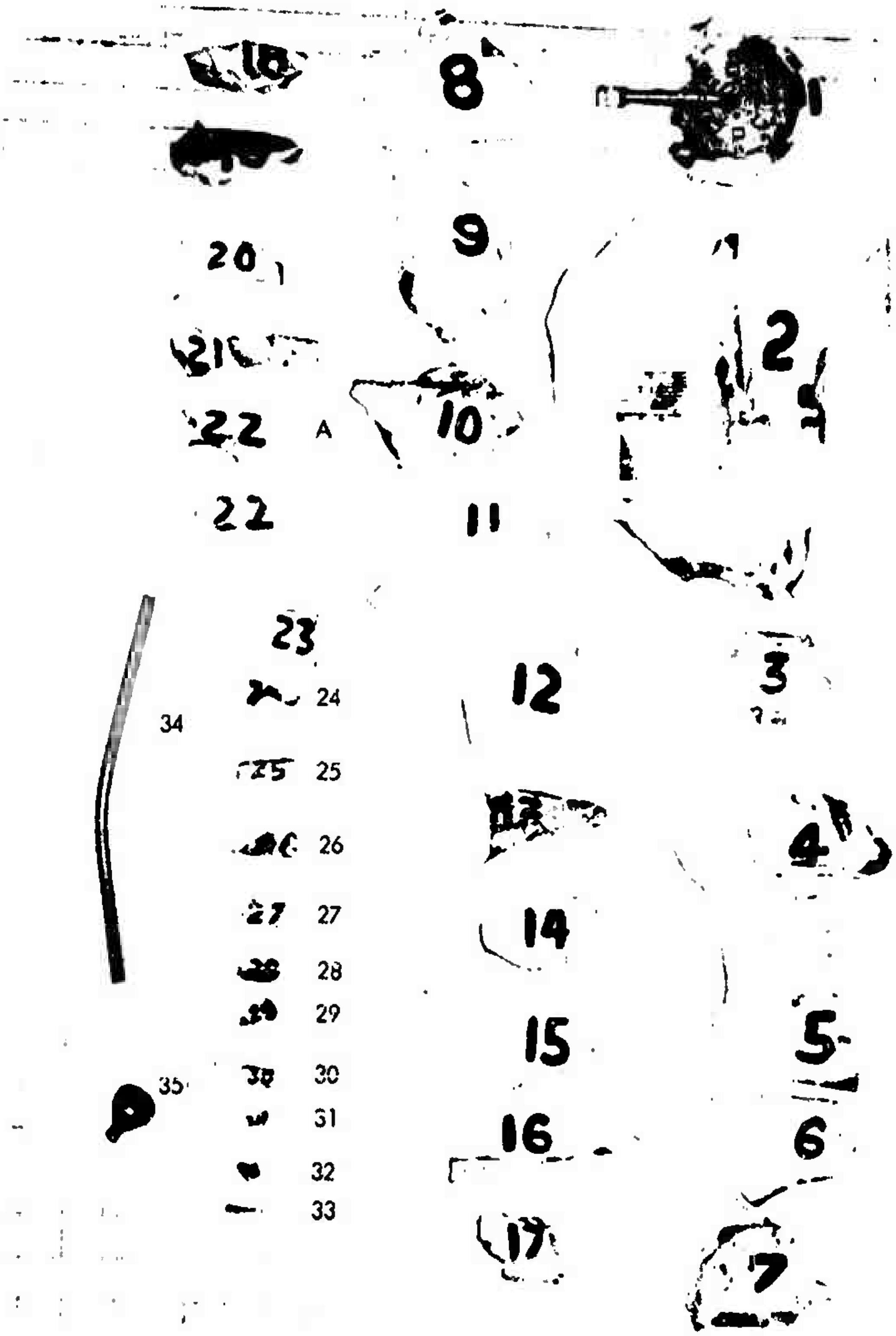


FIG. 11 FRAGMENTS FROM TANK B (2" LINE SPACING)

FIG. 12 FRAGMENTS FROM TANK E (2' LINE SPACING)

Figure 13

Measured Fragment Velocities

Tank	Breakwire Velocity	Strobe System Velocities			
		Fragment Number (1)	Time (2) Interval	Distance Traveled(3)	Velocity VA (4)
A	No Data	1	0 to 1.50	1.52	1010
			1.50 to 3.00	1.56	1040
			3.00 to 5.00	1.50	750
			0 to 5.00	4.58	918
		2	0 to 1.50	1.56	1040
			1.50 to 3.00	1.61	1070
			3.00 to 5.00	1.86	930
			0 to 5.00	5.03	1000
		3	0 to 3.00	3.10	1030
			3 to 5.00	1.73	865
			0 to 5.00	4.83	967
B	1215 ± 50	1	0 to 3.00	2.76	920
			3.00 to 4.50	1.29	860
			0 to 4.50	4.05	900
		2	0 to 3.00	2.96	986
			3.00 to 4.50	1.32	880
			0 to 4.50	4.28	950
C	1270 ± 80	1	C to 3.00	3.60	1200
			3.00 to 4.50	1.53	1020
			0 to 4.50	5.20	1150
D	1400 ± 90	No	Strobe Data		
E	1470 ± 100	No	Strobe Data		

(1) Fragments identified in Figures 4.9 through 4.18
(2) Times in milliseconds
(3) Distance in feet
(4) VA - Average velocity in ft/sec over the time interval given

A COMPUTATION AID FOR ESTIMATING BLAST DAMAGE FROM ACCIDENTAL DETONATION OF STORED MUNITIONS

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SUMMARY

A computational aid for the rapid assessment of potential hazards from blast during the accidental detonation of stored munitions was prepared. Four munitions, the MK82 500-lb bomb, the M117 750-lb bomb, the M107 155-mm shell and the M437A2 175-mm shell, stored in module type open barricaded pads, in above ground magazines and in standard earth covered igloos were considered. Targets considered included personnel standing in the open, frame structures, and unarmored military vehicles.

This information is presented on a circular slide rule. The basic equations for quantity-distance for various damage and injury levels are presented. A description of the slide rule and a sample calculation, demonstrating its use, are presented.

INTRODUCTION

When a stack of munitions detonates accidentally, two major effects occur, (1) a strong blast wave is propagated and (2) a large number of fragments are propelled away from the stack. Compilation of available explosion effects information to estimate risk of damage or injury from blast at various

distances from the source to the target led to the preparation of a mechanical computation aid for rapidly assessing the potential hazards from the blast effect.

The targets are standing personnel in the open, frame structures and trucks. Four munitions were considered in the detailed evaluation: the 155-mm M107 projectiles, the 175-mm M437A2 projectiles, the MK82 500-lb bomb and the M117 750-lb bomb. These munitions are normally stored within earth-covered igloos, above ground magazines, or within earth revetments in amounts ranging from several units up to 500,000 lbs of explosive weight. Previous experimental studies on the accidental detonation of such stored munitions have established the minimum intermagazine separation distances to prevent communication of the explosions to adjacent magazines. The Department of Defense Explosives Safety Board has further established quantity-distance relationships for safety to various other targets, such as inhabited buildings and public highways. The need may arise for assessing the potential hazard to various targets which, for a variety of reasons, may not fall under the guidelines published by the DDESB. For example, a temporary munition storage area may be required in an area where houses already exist or where a number of personnel may normally be found during the course of the day. The computation aid allows the repid assessment of the hazards to these potential targets and of the effects of deviations from the recommended quantity-distance.

Sufficient data on blast effects, both on the nature of the blast generated by the stack and on the response of the specified targets are available. This information was gathered and reduced into a form suitable for a mechanical aid.

First the description of the munitions and munition storage pertinent to the evaluation of these hazards are presented. Then a summary of the data available on blast effects is given, together with a description of the damage or injury levels associated with blast. The range-yield relations for such damage levels are given. Simplified, conservative relations suitable for representation on a mechanical computation aid are derived. The slide rule is described and a sample calculation, illustrating its use, is presented.

FACTORS

The several factors that describe the munition storage, the weapon characteristics, the stack characteristics and the mode of storage that are pertinent to the blast and shock are given below.

Four munitions were chosen for detailed study in this project. Other munitions and bulk explosives are given briefer treatment. Table 1 presents basic data on single rounds of these munitions, the 155-mm and 175-mm shells and the 500-lb and 750-lb bombs. These four munitions are in extensive use, have a large range of parameter charge weight to metal weight, C/M. Four different explosive fillers are selected to provide a wide range, although other explosive fillers may be used in these weapons.

Table 2 shows the equivalent TNT weight of each of the four explosives (JMEM 1970).

These munitions are normally stored in rectangular piles. The parameters describing the stack are the number of munitions in the two horizontal directions and the vertical direction, the total number of munitions in the stack, the spacing between individual munitions and the orientation of the munitions within the stack.

The normal storage of the munitions is within one of three barricaded structures. The munitions may be surrounded by an earthen revetment such

that the line of sight from the top of the munition stack to the top of the earth mound is greater than 2° from the horizontal. This revetment is usually on three sides, only the fourth side is open for access to the stack. The munitions may be stored within an earth covered, steel arch igloo. The earth cover is at least two feet thick at the crown and covers the top sides and rear wall; the front wall is concrete with steel doors. Typical dimensions of such a structure are 26 feet wide and 60 to 80 feet long. The munitions also may be stored in above ground magazines, which are structures with concrete walls. Typical plan dimensions of a magazine are approximately equivalent to the igloo dimensions.

BLAST EFFECTS

When the stack of munitions accidentally detonates, an intense heat wave is propagated into the area surrounding the stack. The stack is roughly cubical and the orientation of the stack is unknown. Blast effects are approximated by determining the blast from a hemisphere of the same effective yield. The effective yield is the total equivalent TNT yield reduced to account for the energy lost to the fragments. Because of the configuration of the stack, the blast propagation is enhanced in certain directions; the maximum enhancement is evaluated and selected. The effect of a barricade or magazine may reduce the blast effects at a distance. Each of these effects is discussed below.

Blast-Range Parameters from a Hemispherical Charge

The blast-range parameters from the detonation of a hemisphere of TNT are chosen as the starting point for the evaluation of blast from the stored munitions. These parameters have been established by Kingery (1966) from compilations of experimental data covering a wide range of explosive weight.

The parameters are peak overpressure, positive phase impulse, positive phase duration of the pressure profile and extended to include dynamic pressure impulse by Richmond and Fletcher (1971).

When a munition, such as those considered here, detonates, not all of the energy released goes into the blast wave. A fraction of the explosive energy is used to break up the case and to propel the fragments. Several estimates of the energy available to the blast wave based on theory and experiment are reported in the literature. The most common estimate of the energy available to the blast wave is the modified Fano formula (JMEM, 1970).

$$\frac{W_{eff}}{W} = 0.6 + 0.4 \left(1 + \frac{2}{C/M}\right)^{-1}$$

where: W_{eff} is the energy available for blast

C/M is the charge weight-to-metal-weight ratio.

Table 3 shows this ratio for the four munitions considered. The charge weight in the ratio C/M is taken as the equivalent TNT weight.

The detonation of charge which has a shape other than spherical or hemispherical propagates a blast wave which shows a more complex spatial structure. Experiments have been conducted on the detonation of rectangular parallelepipeds (Adams, Sarmousakis and Sparraza, 1949); cylinders and disks of explosive material (Wisotski and Snyer, 1965; Fugelso, Fields and Byrne, 1971). For cubes and cylinders with $L/D = 1$, the peak overpressure versus range in the direction normal to a force or to the axis of the cylinder is enhanced relative to the same overpressure-range curve for hemispherical charge. In the overpressure range $3 \leq \Delta P \leq 40$ psi, the ratio between the two curves ranges between 1.1 and 1.5, with a mean value of 1.2. Once an increase in overpressure is established, this amplification persists at

least to ranges where the overpressure is about 1.0 psi. An experiment on the detonation of a disk array of TNT shows the persistence of the amplification factor to overpressure of 0.1 psi (Fugelso, Fields and Byrne,1971). In other directions, the peak overpressure range curves for the angles and cylinders can be less than hemispherical curves. In the extreme geometry of disk, the maximum amplification is about 1.5 in the same overpressure range.

An earth revetment or barricade has a negligible effect on the propagation of blast at large distances from the barricade (Wiedermann, 1971). The blast is reduced at the ground for a short distance behond the revetment ($r < 5h$, where h is the height of the revetment), but the blast wave reforms at longer distances.

Igloo Effects

When the stack is contained within an earth-covered igloo, the blast wave at large range is reduced as a fraction of the blast energy is absorbed in breaking up the earth cover and in the energy of the fragments of the structure. A sequence of experiments (ANESB 1947, 1946a, 1946b) evaluated the attenuation of the blast as a function of the earth cover-weight-to-charge-weight ratio. At a fixed scaled distance and a given value of the cover-to-charge ratio, an effective charge weight can be defined by

$$\frac{\Delta P(\text{covered})}{\Delta P(\text{open})} = \left(\frac{W_{eff}}{W}\right)^{1/3} = k^{1/3}$$

The range of this factor is quite small for the range of typical igloo size and explosive contents when the peak overpressure in the open varies between 1 and 40 psi. For the purpose of preparing a computation aid, a single value of k was chosen, rather than requiring the knowledge of the cover-to-charge ratio. The single value was chosen by considering a standard igloo 26 ft x 80 ft completely filled with munitions with a total charge weight of 200,000

pounds of TNT. For this configuration,

$$k \sim 0.8$$

The blast parameter from the detonation of a stored munition then is represented by the blast from an equivalent hemisphere, where the equivalent yield is calculated by

$$W_{stack} = 1.2\, W\, k\, F$$

where

W is the total charge weight of the stack in lb. of TNT,

F is the modified Fano formula using C/M,

k is an attenuation factor for the mode of storage

k = 1.0, munitions stored in the open or contained within an earth revetment or in an above ground magazine

k = 0.8, munitions stored within a standard steel arch, earth-covered igloo.

DAMAGE AND INJURY CRITERIA

Three targets are selected for evaluation of potential damage from blast. They are standing personnel in the open, frame structures and trucks. For each target we identify the several mechanisms of damage or injury and determine the value of a blast parameter, such as peak overpressure, associated with the degree of intensity of damage. The value of blast parameter is converted into an isodamage curve in the yield-range plane.

Damage to Frame Structures

Damage to frame structures is caused by failure of structural components in response to the overpressure as a function of time. Bounds for the pressure-duration relationship can be obtained by considering the response to a rectangular pressure pulse with the peak overpressure and impulse equal to the

free-field values. The two bounding forms for a pressure-duration relationship that must be satisfied to just break a structural element are:

$$\Delta P = \Delta P_c \qquad t_x > \frac{1}{2\omega}$$

$$\Delta P = \frac{\Delta P_c}{2\omega t_x} \qquad t_x < \frac{1}{2\omega}$$

For a single structural element ΔP_c is the overpressure at which the element fails under an infinite duration step load and ω is its natural frequency. The parameter t_x is defined:

$$\Delta P t_x = I_+$$

where I_+ is the positive phase impulse

In the range $0.8 \leq \Delta P \leq 40$ psi, the following approximation holds (taken by least square fits to the Kingery TNT hemisphere curves):

Peak overpressure:

$$\Delta P = 569.5\lambda^{-1.711} \text{ psi}$$

Positive phase impulse:

$$I_+ = 67.42\ \lambda^{-0.9243} W^{1/3} \text{psi-msec}$$

where $\lambda = R/W^{1/3}$

W = yield in pounds TNT

R = range in feet

(More generally, we consider $\Delta P = f(\lambda)$, but we will use the power law expression here to derive a convenient form for t_x.) In terms of the blast parameter:

$$t_x = 0.1184\ W^{1/3}\ \lambda^{0.7879} \text{ msec}$$

The first form is the bound for a load whose duration is long compared to the period of free vibration of the structure and is dependent on a critical value of overpressure. The second form is a bound for a load whose duration is short compared to the period of the structure and is an impulse

criterion. We can express both forms in the yield-range plane by expressing ΔP and t_x in terms of W and R. We take the smaller range at fixed yield to establish the yield-range isodamage curve.

$$W = \left(\frac{\Delta P_c}{569.5}\right)^{1.753} R^3 \qquad W > W_1 (R)$$

$$W = \left(\frac{\Delta P_c}{134.8\omega}\right)^{1.560} R^{1.440} \qquad W < W_1 (R)$$

where W_1 (R) is:

$$W_1 (R) = (.2368\omega)^{-14.14} R^{-11.34}$$

If we use the overpressure criterion, we obtain an upper bound for range in the yield-range plane.

There are many structural elements in a frame structure which may fail during the application of the blast, each having different values of W and ΔP_c. The failure of each element can be represented by a curve of the form shown in the R-W plane. The overpressure criterion gives an upper bound for each element.

We take definite values of ΔP_c as representative of the degree of major structural damage to frame structure. Tests of the damage of frame structures by blast from various yield explosions have been reported in the literature (Wilton, 1970) with assessments of the damage. The values of ΔP_c are generated from estimate of damage to frame houses by large yield blasts. Approximately 10% of his total damage is deducted, since the plaster and glass damage are included in his figure. Table 4 gives the damage levels.

These curves are ploted in Figure 1. The example plotted in Figure 1 is for structures whose natural period is 160 msec/cycle, which is typical of a wood rafter. Also plotted are Wilton's experimental points and Custard's et. al. (1970) calculation of damage based on Sewell's criterion that the

impulse exceeds a critical value with a critical period. Each tested structure is plotted with an indicated damage level including glass and plaster damage and major structural damage. Empirical fit of the form $R/R_1 = (W/W_1)^{0.435}$ (Johnson 1967), for the 10% damage level is also included. The World War II data on A-, B-, and C-level damage from 500-4000 lb. bombs on small steel factories are also plotted (Kennedy, 1946). Westine (1971) suggested fitting the same damage level through a curve of the form:

$$R = \frac{kW^{1/3}}{\left(a + \frac{b}{W} + \frac{c}{W^2}\right)^{1/6}}$$

where k, a, b and c are empirical constants.

This form is asymptotic to a peak overpressure criterion at large yield and to an impulse criterion at small yields. He presents a fit for data for brick houses. For complete destruction, this is:

$$R = \frac{9.5\, W^{1/3}}{\left[1 + \left(\frac{7000}{W}\right)^2\right]^{1/6}}$$

This curve is also plotted. It agrees with the A-level damage (or complete destruction) data and also agrees with ΔP_c = 12 psi for this type of structure (Wolosewick, private communication). Also included is the threshold for glass breakage which is taken as ΔP_c = 0.25 psi.

The value of W_1 for these damage levels occurs between 100 and 1000 lb. of TNT. A reasonable approximation for the damage is given by the overpressure criterion. The ranges at which damage is overestimated occur for very small charges. The hazard evaluation from munition storage normally involves larger total charge weights, and the overestimate of range (which is conservative) for small charges is not considered important.

Injury to Personnel

Personnel are affected by blast waves in two major modes: (1) by damage to internal organs by overpressure, denoted primary damage; and (2) by translation followed by striking an obstacle, denoted tertiary damage. The former damage mechanism to lungs has been investigated by Bowen et. al. (1968) and von Gierke (1968), and to ears by Hirsch (1966). The latter mechanism has been investigated by Richmond et. al. (1966, 1968) and Bowen et. al. (1968).

Data on primary injury to personnel have been obtained by experimentally determining overpressure-duration relationships for animals, and extrapolating these to humans. The relationship to some specified degree of lung damage fatality is:

$$\Delta P = \Delta P_c (1 + 6.76\, t_+^{-1.064})$$

where t_+ in the positive phase duration

$$t_+ = 1.188\lambda^{0.3473}\, W^{1/3}\ \text{msec.}$$

Table 5 shows the free field overpressure, ΔP_c, associated with various levels of lethality at infinitely large durations (Bowen et. al. 1968). Von Gierke (1968) considered the human lung as a one-degree of freedom system with damping. The derived relationship has the same form as the damage criteria for the frame structures and is also very close to the empirical curve. For the human lung the fundamental frequency, ω, is between 100 and 1000 cps.

Eardrums are damaged in response to overpressure alone as the characteristic period of the ear vibration is small compared to the duration of a blast profile from one pound of TNT. Hirsch (1966) has established the relationship between the overpressure and the probability of eardrum rupture (Table 6).

Injury to personnel by tertiary effects is related to the maximum translation velocity that the body can attain during the blast. It is assumed that the injury is caused when the body strikes an obstacle at maximum velocity. The probability of lethality for body impact has been determined as a function of the impact velocity. Lethality criteria have also been determined for impact of the head against an obstacle. Table 7 shows the impact velocity associated with several levels of lethality (Richmond et. al. 1966).

The acceleration of the body in response to the blast is given by the dynamic overpressure impulse. The maximum translational velocity is related to this impulse by

$$V_m = C_D A\ J_{+/M}$$

where: J_+ is the dynamic overpressure impulse

M is the mass of the body

C_D is the drag coefficient of the target, assumed here to be unity

A is the presented cross-section area of the body to the blast.

An approximation for the dynamic overpressure impulse for a hemispherical TNT source, adapted from the reflected spherical source of Richmond and Fletcher (1971) is

$$J_+ = 266.4\lambda^{-2.3201}\ W^{1/3}\ \text{psi-msec}$$

Each maximum translation velocity defines a critical level of the dynamic overpressure impulse, J_c. When $J_+ \geq J_c$, the damage is assumed to occur and the equality defines a yield-range curve for that level of lethality. We calculate J_c for a typical grown male adult, using a weight of 155 pounds and an area of 8 square feet. See Table 7.

<u>Damage to Trucks</u>

One source of blast damage to trucks results from overturning the vehicle. If the blast overpressure and dynamic pressure time histories are known, the

turning of the vehicle can be calculated (Custard et. al. 1970). A second source of damage is the severe deformation of structural components in response to the overpressure.

For a vehicle subjected to broadside blast impulse, responding in rigid rotation about an axis at the ground surface in the plane of the front and rear wheels away from the explosion source, overturning occurs when the dynamic overpressure impulse, J_+, exceeds a critical value, J_c.

The values of J_c for incipient overturning of typical trucks range between 70 and 110 psi-msec (Custard et. al. 1970). Ethridge (1961) measured the overturning and blast damage to jeeps and trucks side-on and face-on to the air blast from a 100-ton TNT hemispherical burst. Incipient overturning occurred for $110 \leq J_c < 170$ psi-msec. We take 90 psi-sec as a typical threshold value. When the truck is just barely overturned, it is not likely to be damaged severely and when it is righted, it can probably be driven away. When the dynamic overpressure impulse exceeds the threshold, the truck will be translated after overturning with increasing possibility of damage as the translation velocity increases. Tests of damage to parked trucks in response to blast from nuclear burst shows that the threshold of overturning is between 60 and 100 psi-msec and complete damage after overturning occurs when J_c is greater than 500 psi-msec (Glasstone, 1964). Ethridge's (1961) measurements of damage to blast overturned jeeps shows the severe damage limit between 250 and 350 psi-msec. We use a value of 300 psi-msec as the criterion for complete destruction to a military vehicle due to overturning.

Ethridge also measured damage to jeeps and trucks face-on to the explosion and found that no overturning occurred. Vehicles were damaged by severe distortion of structural components, such as hoods, frames, etc. This damage in relation to air blast is estimated in much the same manner as

damage to frame structures. The criteria for levels of damage in this mode is overpressure. From Ethridge's experimental data, values of 6 psi for the threshold of damage and 30 psi as the level above which total damage occurs is selected.

DESCRIPTION OF THE SLIDE RULE

A circular slide rule type computer was designed which presents to the user the information described above in a convenient and compact form. The computer utilizes both sides of a 10-inch disc and one slightly smaller movable disc on each side.

The front side of the computer deals with problems related to damage resulting from blast effects of explosives stored in bombs or shells. It is illustrated in Figure 2. The back of the computer deals with problems related to blast effects resulting from detonation of bulk explosives and explosives loaded in light-cased munitions where the casing factor is negligible. The back is illustrated in Figure 3.

The parameter which determines the effects of an explosion of a stack of weapons or a given amount of bulk explosives is the effective yield of the explosion in terms of pounds of TNT. This is determined on the slide rule by making one setting.

In the case of a stack of bombs or shells, one enters on the front of the computer by setting the number of weapons on the proper scale in the window at the top (labelled A in Figure 2) or by setting the weight of the explosive filler at the proper hairline at the top left of the computer (labelled B in Figure 3). This setting determines the effective yield, which is given in the window denoted by C, and determines all other pertinent damage effects, so that once this setting is made the top disc should not be moved.

The effective yield shown in this window takes into account the casing factor, the TNT equivalent of the particular explosive being considered, and a factor of 1.2 to correct for the maximum directional effect since the blast wave is not uniform in all directions. For example, one MK 82 bomb contains 192 pounds of H6. Thus, setting the black hairline to 1 on the MK82 scale yields:

$$192 \times \underbrace{.695}_{\text{casing factor}} \times \underbrace{1.25}_{\text{TNT equivalent of H6}} \times \underbrace{1.2}_{\text{directional effect}} = 199.2$$

on the effective scale. In the case of weapons stored in earth covered igloos (where the red hairline is used), a factor of 0.8 is also included to account for the attenuation of the blast effects. Thus setting the red hairline to 1 on the MK82 scale yields 199.2 x 0.8 = 159.36 on the effective yield scale. These factors are based on information presently available from blast measurements and igloo tests. All effects scales described below are coordinated with the effective TNT yield in window C.

The scales denoted by D in Figure 2 give the relationship between the distance from the explosion and the peak overpressure occurring at that distance and are based on Kingery (1966). This scale indicates the distances at which glass breakage, threshold damage, 50 percent damage and total damage will occur to frame structures and threshold and total truck crushing damage due to a particular explosion. This scale also indicates the distances for threshold, 10, 50, and 90 percent of personnel incurring ear damage, and the distances for threshold, 10, 50, 90, and 99 percent of personnel incurring lung damage. These percentages refer to the degree of damage or to the portion of the population affected.

The scales denoted by E give the relationship between the distance from the explosion and the dynamic overpressure impulse occurring at that distance. The distances at which threshold, 50 and 99 percent of the population will incur head and body injuries and the distances at which threshold truck overturning and total truck damage will occur is also given on these scales.

The scale denoted by F in Figure 2 gives the intraline distances for barricaded and unbarricaded weapons and is based on Table 5-6.3 in DOD publication 4145.27M, DOD Ammunition and Explosives Safety Standards, dated April, 1971. This table is based on the formulas $D = 9W^{1/3}$ for barricaded weapons and $D = 18W^{1/3}$ for unbarricaded weapons, where D = distance in feet. This scale, as well as the scales for DOD Distances (labelled G in Figure 2) are intended as guides for the user to indicate approximate distances, but the DOD manual referenced above should be consulted for compliance purposes.

The scales denoted by G in Figure 2, give the distances from the stack of weapons to inhabited buildings, highways and passenger railroads, and are based on Table 5-6.4 in DOD publication 4145.27M referenced above. If the reading should fall in the red portion of the scale, fragment protection considerations may override blast protection considerations. To determine whether this is the case, consult the table of minimum distances for the particular weapon being considered (directly below the window denoted G) if this minimum distance is greater than that indicated by the arrow, fragment protection considerations will control.

The scales indicated by H in Figure 2 gives the relationship between the distance from the explosion and the positive phase impulse at that distance.

The back of the computer deals with problems related to detonation of bulk explosives or explosives in thin-cased munitions. It is essentially the

same as the front except that one enters by setting the hairline to the weight of the explosives on the proper scale in the window at the top, indicated by A in Figure 3. Once this setting is made, all the information is read exactly as described for the front of the computer except that for DOD distances (read in window G), those distances for 1 to 50 lbs. TNT may be applied only when fragments and debris are completely defined. On this side of the computer, the effective yield contains all adjustment factors except the case factor.

For explosives other than the four indicated, the table of TNT equivalents (denoted by B in Figure 3) may be used to obtain a factor by which the weight of explosive should be multiplied to enter the TNT scale in window A (Figure 5). The damage effects may then be read as before.

It is also possible to solve inverse type problems on the computer. For example, it can be used to determine the maximum number of weapons of a certain type which may be stored in a stack a given distance from a building. This distance is set on the scale denoted G in Figure 4, and the number of weapons is read on scale A. Here again, one must determine whether blast effects or fragments will be the controlling factor. An example of the calculations that may be performed on the slide rule is given below. (See Figure 2 for the setting.)

A stack of 2500 175-mm projectiles loaded with Comp. B is contained in an earth-covered igloo. (Note that this is about half the capacity of a 26 ft by 60 ft igloo.) At what distances will undesirable effects occur due to an accidental explosion?

SOLUTION:

In the window (A) at the top of the front of the computer, set the red hairline to 2500 on the M437A2 scale. The total Comp. B filler weight

(window B) is about 78,000 pounds. The accidental explosion would result in an effective yield of approximately 54,000 pounds TNT, (Window C)

The other scales indicate that:

a. Threshold damage to frame structures occurs at about 1850 feet, while total damage occurs at about 550 feet. (Window D)

b. Threshold ear damage occurs at about 900 feet, while threshold lung damage occurs at about 310 feet. (Window D)

c. Threshold truck crushing damage occurs at about 490 feet. (Window D)

d. Threshold head injury due to tertiary effects occurs at about 370 feet, while threshold body injury occurs at about 300 feet. (Window E)

e. Threshold truck overturning occurs at about 290 feet, while total truck overturning damage occurs at about 175 feet. (Window E)

f. Intraline distances for barricaded and unbarricaded weapons should be about 340 feet and 680 feet, respectively. (Window F)

g. The distance to inhabited buildings due to blast effects should be about 1500 feet, and the distance to public highways and passenger railroads due to blast effects should be about 900 feet. (Window G) Since these are both in the red portions of the scales and the minimum distance for the M437A2 is 2070 feet, fragment considerations would control for inhabited buildings and for public highways and passenger railroads at these distances.

The scales in Figure 3, the slide rule for bulk explosive effects, is set for 78,000 lbs of Comp. B (the same filler weight as in the previous example) stored in an igloo. The corresponding distances can be read from this figure.

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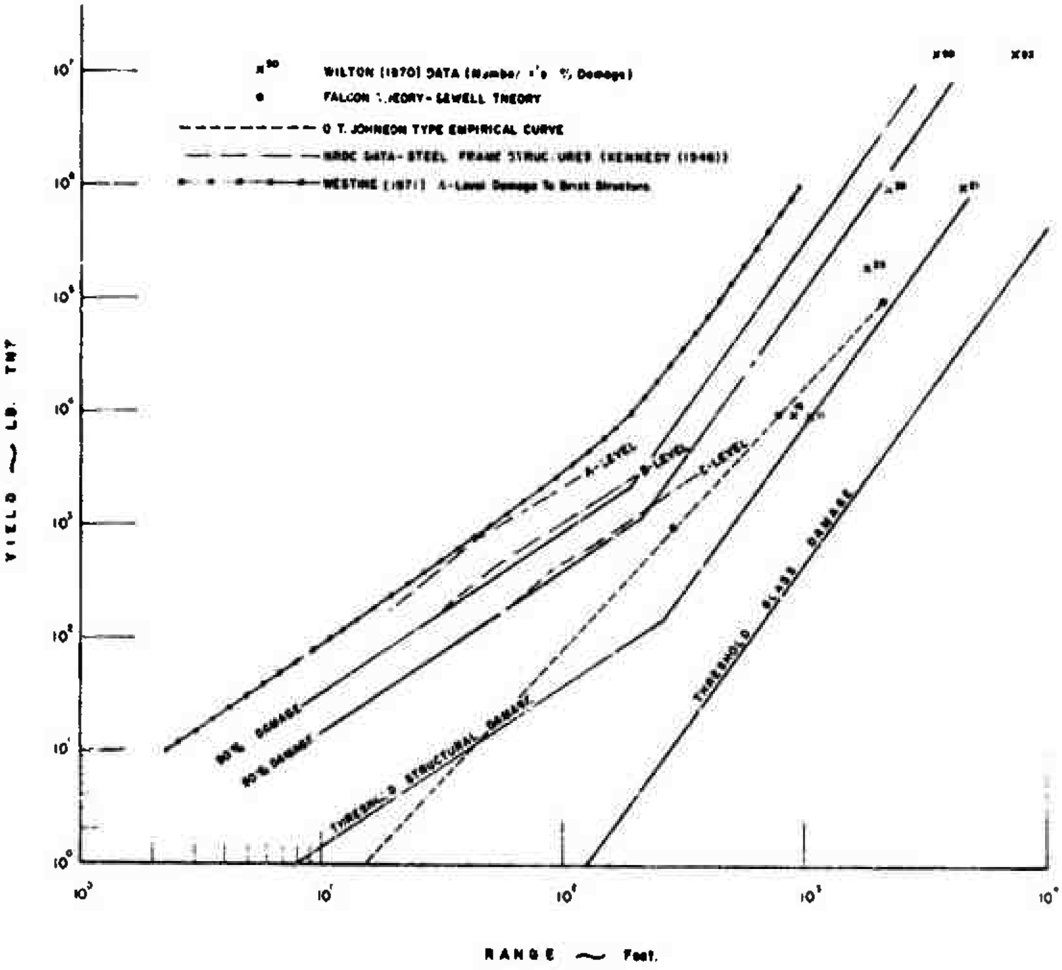

Figure 1, ISODAMAGE CURVES FOR A FRAME STRUCTURE DAMAGED BY AIRBLAST

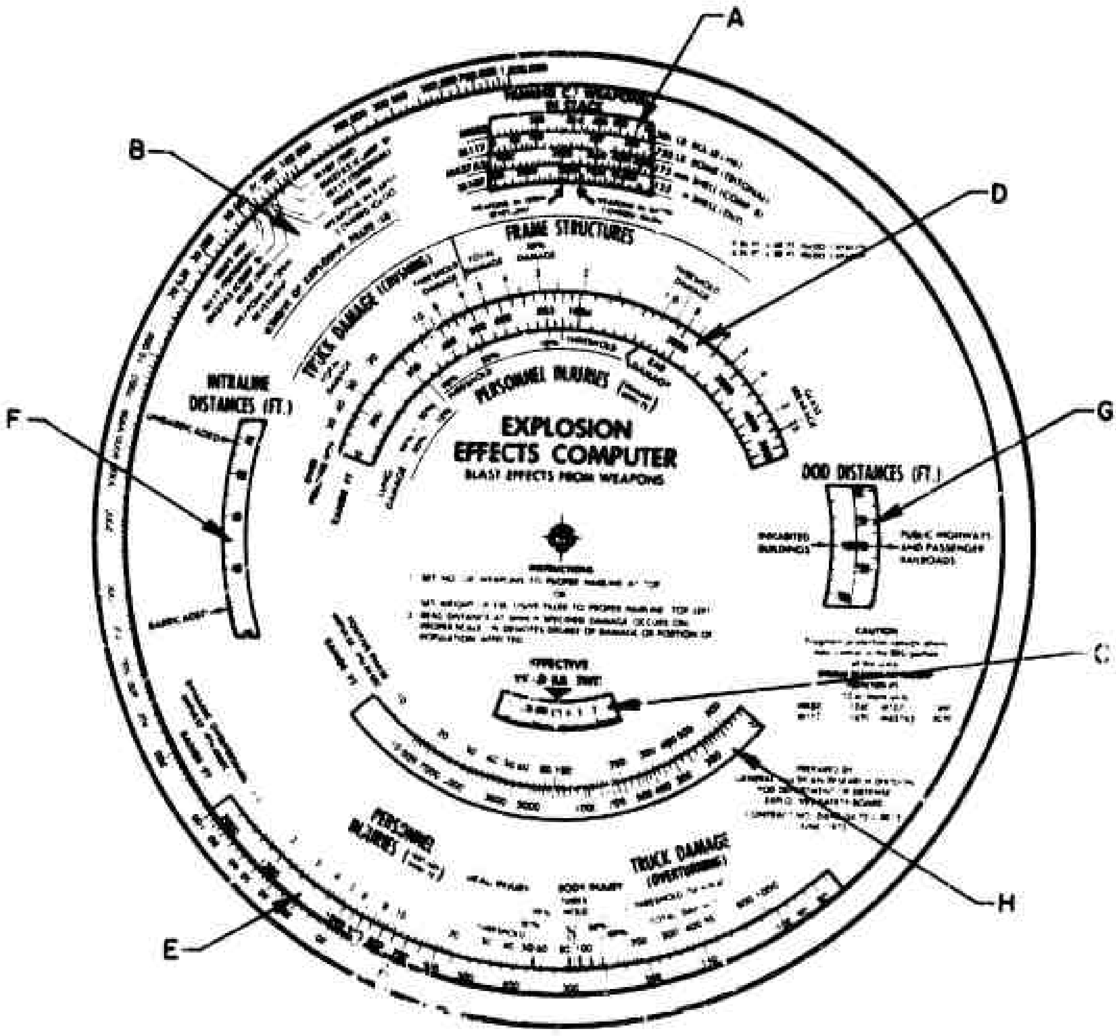

FIGURE 2, FRONT SIDE OF SLIDE RULE

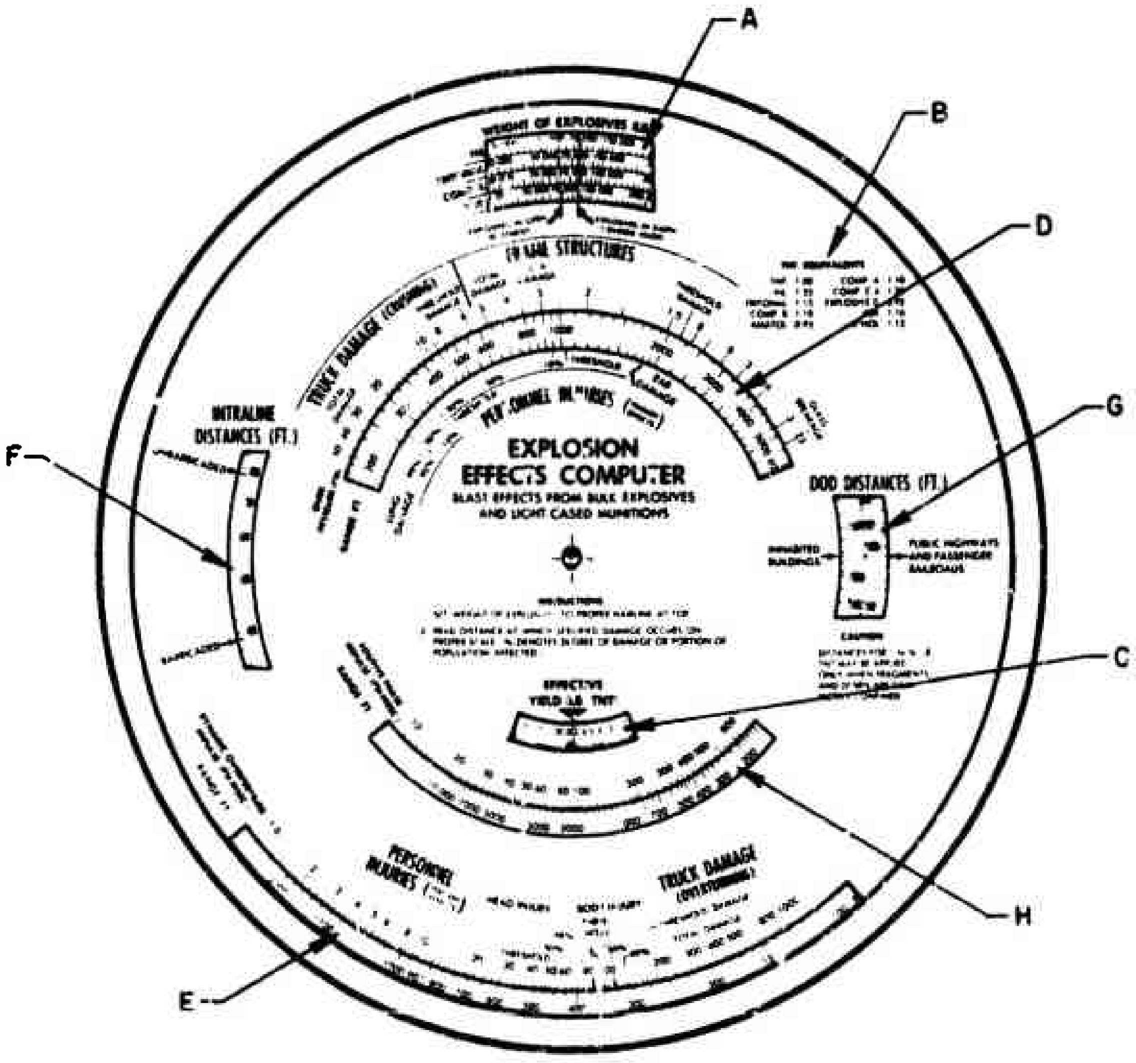

FIGURE 3. BACK SIDE OF SLIDE RULE

Table 1 WEAPON CHARACTERISTICS

Weapon	Designation	Explosive Filler	Total Weight, lb	Explosive Weight, lb	Length, Inches	Diameter, Inches	Charge Wt./Metal Wt. = C/M
500-lb Bomb	MK82	H-6	500	192	56.15	10.75	0.62
750-lb Bomb	M117	Tritonal	737	386	51.41	10.10	1.10
155-mm Shell	M107	TNT	94.8	15.1	26.80	6.10	0.19
175-mm Shell	M437A2	Comp. B	144	30.8	34.50	6.90	0.28

Table 2 EQUIVALENT FACTORS FOR VARIOUS EXPLOSIVES RELATIVE TO TNT

Explosive	Factor
TNT	1.00
H-6	1.25
Tritonal	1.13
Comp. B	1.10

Table 3 EFFECTIVE YIELD FOR SELECTED MUNITIONS

Munition	Explosive	Charge Wt., lb.	Equivalent Wt. TNT, lb.	Effective C/M	Fano Factor	Effective Wt. TNT, lb.
MK 82	H-6	192	240	0.78	0.712	171
M117	Tritonal	386	436	1.24	0.753	328
M107	TNT	15.1	15.1	0.19	0.635	9.58
M437A2	Comp. B	30.8	33.9	0.30	0.652	22.10

Table 4

CRITICAL OVERPRESSURE FOR DAMAGE TO FRAME STRUCTURES

Damage	ΔP, psi
Threshold Glass Breaking	0.25
10% Damage	0.9
50% Damage	3.0
90% Damage	5.0

Table 5

CRITICAL OVERPRESSURES FOR LUNG DAMAGE TO HUMANS

Damage	Free-Field Peak Overpressure, psi
Threshold	14.5
10% Lethality	17.5
50% Lethality	20.5
90% Lethality	25.5
99% Lethality	29.0

Table 6

PROBABILITY OF EARDRUM RUPTURE

Probability of Eardrum Rupture	Free-Field Peak Overpressure, psi
Threshold	2.4
10%	2.8
50%	6.3
90%	12.2

Table 7

LETHALITY DUE TO CRITICAL IMPACT VELOCITY AND CRITICAL IMPULSE
(V_m in ft/sec and J_c in psi-msec)

Lethality	Body		Head	
	V_m	J_c	V_m	J_c
Threshold	20	83.6	13	54.3
50%	26	108.6	18	75.2
99%	30	125.4	23	96.1

HOUSE DAMAGE ASSESSMENT

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Section 1

INTRODUCTION

During the past 21 years, a series of tests has been conducted in which a variety of residential dwellings were exposed to the air blast from high explosives and nuclear events. These tests were sponsored by several different agencies, including The Defense Nuclear Agency (DNA), the Atomic Energy Commission (AEC), the Department of Defense Explosives Safety Board (DODESB), and the Defense Civil Preparedness Agency (DCPA) (formerly the Office of Civil Defense).

The purpose of this study was to review the reports and data from these tests and summarize the available house-damage data, and to develop means by which the house damage could be evaluated.

The houses discussed in this paper are separated into the following categories:

TYPE I	Two-story, center-hall, wood frame house with a full basement.
TYPE II	Two-story, brick and concrete block, center-hall house with a full basement.
TYPE III	One-story wood-frame, ranch-style house on a concrete slab foundation.
TYPE IV	Two-story, brick apartment house with heavy shear walls (European-type construction).

Subcategories of these houses are as follows:

- Strengthened (blast resistant) versions of above types, and
- Repaired houses which had previously sustained blast damage.

A summary of the tests and houses which are included in this study is presented in Table 1-1. Included in this table are the type of house, the test location, the charge type and size, the peak overpressure, and ground range.

Table 1-1

SUMMARY OF TESTS

TEST NO.	CHARGE SIZE	PEAK OVERPRESSURE (psi)	GROUND RANGE (ft)
	TYPE I HOUSE		
I-1	16.2 kt nuclear	1.8	7500
I-2	16.2 kt nuclear	5.0	3500
I-3	30.0 kt nuclear	4.0	5500
I-4	30.0 kt nuclear	2.6	7800
I-5	10,000 lb TNT	1.3	865
I-6	10,000 lb TNT	1.2	865
I-7	500 ton TNT	1.1	4000
I-8	100 ton TNT	1.6	1660
I-9	500 ton TNT	2.7	2256
	TYPE II HOUSE		
II-1	30.0 kt nuclear	1.7	10,500
II-2	30.0 kt nuclear	5.1	4700
	TYPE III HOUSE		
III-1	30.0 kt nuclear	1.9	10,500
III-2	30.0 kt nuclear	5.1	4700
	TYPE IV HOUSE		
IV-1	50.0 kt nuclear	3.6	7020
IV-2	50.0 kt nuclear	8.6	4245

This work was conducted under the sponsorship of the Defense Nuclear Agency under Contract No. 01-70-C-0011. A report entitled "Summary Report — House Damage Assessment," URS 788-6, is now being reviewed by DNA and will be available in the near future. That report presents the house damage data much more completely than can be done here and also includes data for four additional houses, inclusion of which in this paper might have raised questions of security classification.

Section 2

DAMAGE QUANTITIES
(Objective Assessment)

In the numerous reports reviewed during the study the various test houses were described, and the damage sustained by them on each test was presented in considerable detail. It is frequently difficult, however, from such descriptions, to come to any conclusions about the relative damage sustained by each house, that is, it is difficult to determine whether a house was damaged more as a result of one test than another.

For example, one Type I House (exposed to 1.2 psi from a 10,000 lb charge) experienced significant chimney damage, but there was only one rafter cracked. A second Type I House (exposed to 1.1 psi from a 1,000,000 lb charge) experienced insignificant damage, but 19 out of 26 rafters in the front of the roof failed. Which of the two houses sustained "more" damage?

In this section of the paper, a cost-oriented, quantitative approach is developed which allows such comparisons to be made. It is described as an "objective assessment" of damage, at least in part because different evaluators of damage, using the approach, should come up with the same estimates of damage quantities. In a sense the results are repeatable, and can, therefore, be compared with confidence.

DAMAGE ASSESSMENT PROCEDURE

The damage evaluation procedure used in this section required that the plans and specifications for each of the house types, I through IV, be subjected to a bid analysis procedure commonly used throughout the construction industry. This procedure involves dividing the house in question into its various component parts and (1) calculating the yards of concrete, board feet of lumber, square feet of shingles, linear feet of siding, etc., which were needed to construct the particular type of house; and (2) estimating the hours of labor required to install these various component parts. The result of these

computations is an estimate of the dollar value of these various components which can then be expressed as a percentage of the total value of the house.

The typical breakdown for the various groups of components that make up a Type I (two-story wood frame) House is presented in Table 2-1. The numbers are expressed as a percentage of the total value of the structure.

To perform a damage estimate of a particular house, the quantities of materials damaged (i.e., the number of studs split, the square feet of plaster removed or damaged, the panes of glass broken, etc.) were then computed, and the percentage of each of the elements, shown in Table 2-1, that were damaged or destroyed were determined. By multiplying these percentages by the percent of total value estimate for each of the elements, of Table 2-1, a total damage estimate expressed in percent of the total value of the structure is derived.

Table 2-1

VALUE OF COMPONENT GROUPS FOR TYPE I HOUSE

ITEM	VALUE (percent of total)
Floor and Ceiling Framing	17.0
Roof Framing and Roof Surface	7.0
Exterior and Interior Wall Framing	16.0
Interior Plaster	11.0
Exterior Sheathing and Siding	8.6
Doors	4.6
Windows	4.8
Foundation and Basement	19.0
Miscellaneous: Stairs, Fireplace, Paint, Trim	12.0
TOTAL	100.0

Section 3

TYPE I HOUSE TESTS

INTRODUCTION

The typical Type I House is a conventional center hall, two-story, wood frame structure, 33 ft 4 in. long by 24 ft 8 in. wide, with a full basement and a gable roof (see Fig. 3-1). This house has four rooms on each floor, with a brick fireplace in the living room. The walls are plastered, but the finish coat was omitted to reduce the cost. For the same reason, plumbing, electrical, and heating systems were not included.

TEST DESCRIPTIONS AND RESULTS

As noted in Table 1-1, a total of 9 tests were conducted with the Type I, two-story, wood frame, House. Four of the houses were exposed to the air blast from nuclear devices, and the remaining 5 to the air blast from various quantities of high explosives, ranging in size from approximately 2500 lb to 500 tons. These tests are summarized below.

NUCLEAR TESTS

HOUSE NO.	CHARGE SIZE (kt)	PEAK OVERPRESSURE (psi)
I-1	16.4	1.7
I-2	16.4	5.0
I-3*	30.0	4.0
I-4*	30.0	2.6

* These were strengthened versions of the Type I House.

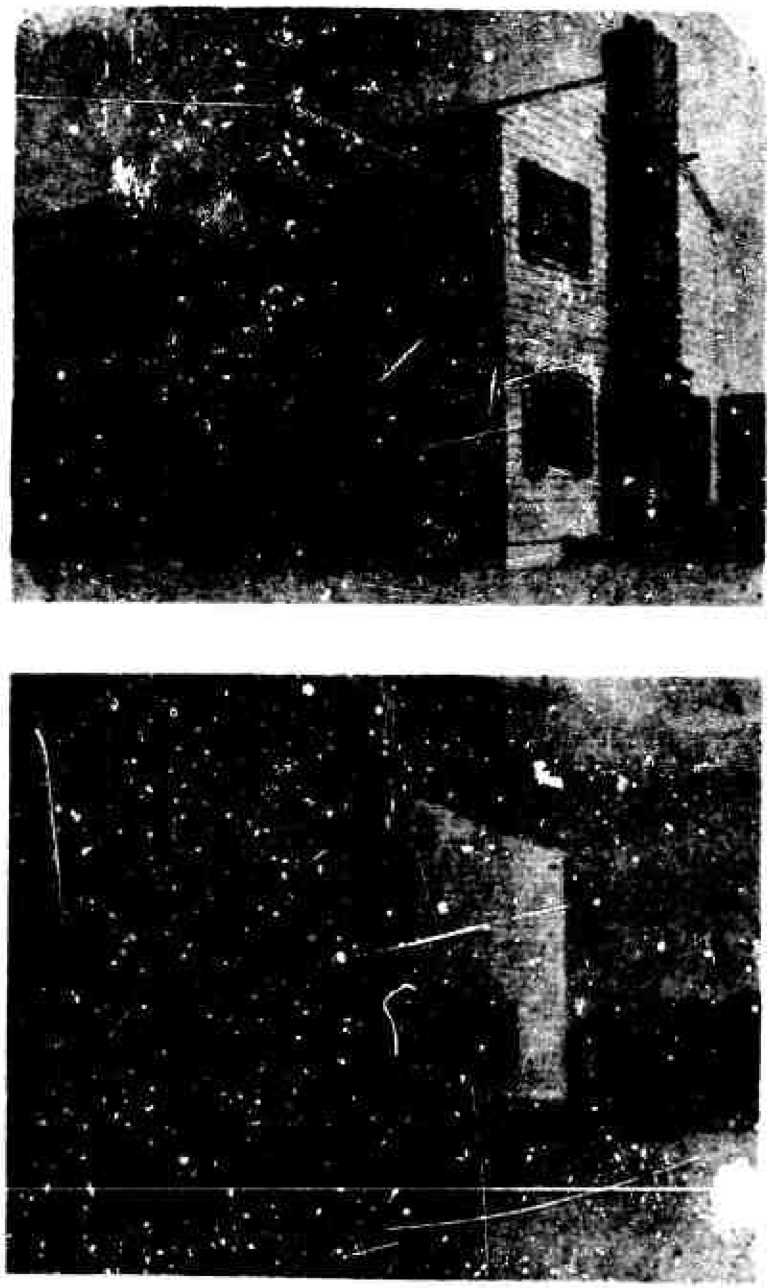


Fig. 3-2. Photographs of Type I House

HIGH EXPLOSIVE TESTS

HOUSE NO.	CHARGE SIZE	PEAK OVERPRESSURE (psi)
I-5	10,000 lb	1.3
I-6	10,000 lb*	1.2
I-7	500 ton	1.5
I-8	100 ton	1.6
I-9	500 ton	2.7

* Two 5000-lb charges detonated approximately 20 msec apart.

Test Description, Houses I-1 and I-2

In 1953, during Operation UPSHOT-KNOTHOLE, two Type I Houses were exposed to a 16.2 kt nuclear device (Annie) exploded at an altitude of 300 ft. House I-1 was located at a ground range of 7500 ft, where the incident peak overpressure was 1.8 psi; House I-2 was located at a ground range of 3500 ft with an incident overpressure of 5 psi.

Test Description, Houses I-3 and I-4

In 1955, during Operation TEAPOT, two Type I Houses were exposed to the blast from a nuclear device with an approximate 30 kt yield (Apple II). These houses were similar in size and layout to the other two-story wood houses described earlier in this section, but were redesigned to resist air blast. The only constraint on the strengthening was that it could not increase the cost of the building by more than 10 percent. The strengthening in general consisted of:

- Stronger foundation connections (4- by 8-in. sill plate with 5/8-in. bolts on 2 ft centers, instead of a 2- by 4-in. sill plate with 1/2-in. bolts on 5 ft centers);
- Larger first floor joists (2- by 10-in. instead of 2- by 8-in.), solid bridging (2- by 1-in.) instead of cross-bridging (1- by 3-in.), and metal joist hangers;

- The second floor framing was increased in size (2- by 6-in. to 2- by 8-in.). Metal joist hangers were used, solid-bridging replaced the conventional cross-bridging in the first and last joist bays and 5/8-in.-round wrought iron framing rods were installed on 48 in. centers in these same joist bays, anchoring the joists to the exterior wall framing;

- The second floor ceiling joists were increased in size (2- by 6-in. to 2- by 8-in.), metal joist hangers were used and wrought iron strap hangers were installed over the center beam to the lower edge of each abutting ceiling joist to strengthen this connection;

- The roof rafters were increased in size (2- by 6-in. to 2- by 10-in.);

- The exterior walls were strengthened by the change to a "balloon" method of framing and increasing the stud size (2- by 4-in. to 2- by 6-in.).

House I-3 was located at a ground range of 5500 ft when the peak incident overpressure was 4 psi; House I-4 was located at 7800 ft when the peak incident overpressure was 2.6 psi.

<u>Test Description, House I-5</u>

In 1967 and 1968 two tests were conducted at the Naval Weapons Center, China Lake, California, under the sponsorship of the Department of Defense Explosives Safety Board (DODESB), to investigate the effect of "simultaneous detonation" on damage parameters at the barricaded inhabited building distance. In the first test a Type I House (no. 5) was exposed to the air blast from a 10,000 lb hemisphere of stacked TNT. The ground range for this test was 865 ft and the peak incident overpressure was 1.3 psi.

<u>Test Description, House I-6</u>

After the first test, House I-5 was restored, as closely as possible, to a like-new condition. The two charges (5000-lb TNT cast hemispheres) were placed 865 ft from the house and detonated at approximately 20 msec intervals. The incident peak overpressure at the house was 1.2 psi.

Test Description, House 1-7

In 1968, during Operation PRAIRIE FLAT at the Defence Research Establishment, Suffield, Alberta, Canada, House 1-7 was exposed to the air blast from a 500 ton tangential sphere of stacked TNT.

House 1-7 was a standard Type 1 House located 4000 ft from ground zero where the incident peak overpressure was 1.1 psi.

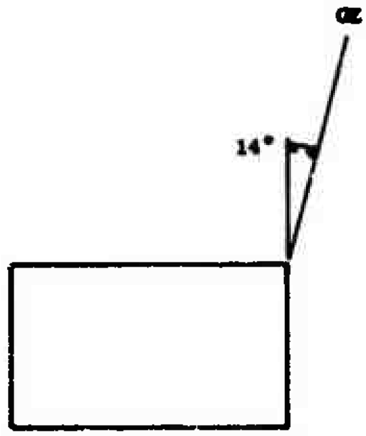
Test Description, House 1-8

In 1969 a series of Ammonium Nitrate/Fuel Oil (AN/FO) tests were conducted at the Defence Research Establishment, Suffield. During this series of tests, the house previously tested during Operation PRAIRIE FLAT (no. 1-7) was repaired and re-exposed to the air blast from a 100 ton hemispherical AN/FO charge. Repairs included replacement of a major portion of the roof, installation of sheetrock (replacing the damaged plaster) in the upstairs back bedroom ceiling and upstairs hall, repair of damaged doors and window frames and replacement of all broken windows. Minor plaster cracks and the like were not repaired.

The house was located 1660 ft from ground zero where the incident peak overpressure was 1.6 psi.

Test Description, House I-9

In the summer of 1970 the house previously tested as I-7 and 1-8 was again exposed to the air blast from a 500 ton TNT charge (Event Dial Pack). Prior to this test the fireplace and chimney were removed and the house was moved from its original foundations and placed on an existing concrete pad 2256 ft from ground zero with the back of the house toward ground zero. The house axis was not exactly perpendicular to a line from ground zero, as shown in the sketch below.



This house had been considerably damaged during the previous AN/FO test and sustained additional damage during removal of the fireplace and chimney and the move to the concrete pad. The majority of this damage was repaired, however. These repairs included: closing the hole left by the removal of the fireplace and chimney with new 2- by 4-in. framing, sheathing, cedar siding, and sheetrock; removing cracked and damaged plaster and broken studs and replacing them with new studs and 1/2-in. sheetrock; replacing broken window frames and windows; and repairing broken roof rafters by placing a new rafter alongside the the old and nailing them together with no. 12 nails on 15 in. centers. In addition, the house was securely fastened to the concrete pad.

Post-test photographs and damage estimates for each of these Houses I-1 through I-9 are presented in Figs. 3-2 through 3-10.

Peak Overpressure (psi) 1.8
Charge Size (kt) 16.2

Positive Phase Impulse (psi-msec) ~ 900
Ground Range (ft) 7500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	12	2.0
Roof Framing and Roof Surface	35	2.5
Exterior and Interior Wall Framing	9	1.4
Interior Plaster	5	0.6
Exterior Sheathing and Siding	0	0
Doors	50	2.3
Windows	88	4.2
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	6	0.7
TOTAL		13.7

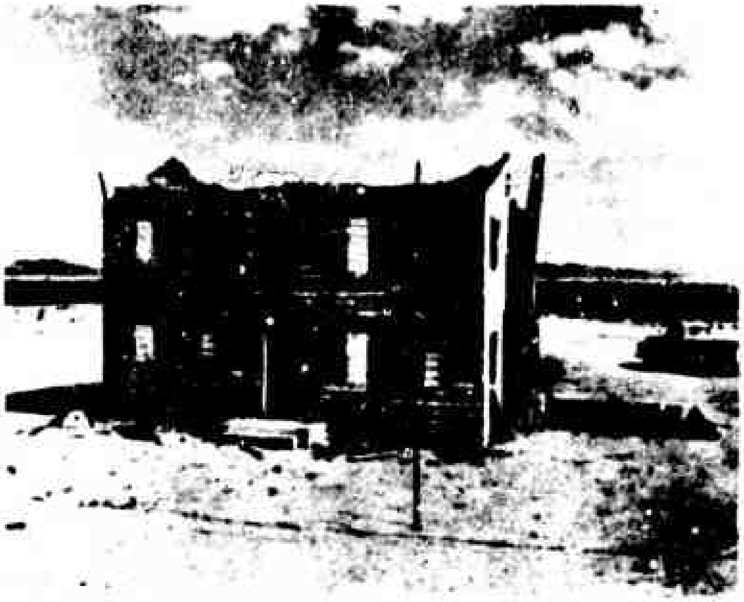
Fig. 3-2. House Damage Summary, House No. I-1

Peak Overpressure (psi) 5.0 Positive Phase Impulse (psi-msec) ~ 1750
Charge Size (kt) 16.2 Ground Range (ft) 3500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	100	17.0
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	100	16.0
Interior Plaster	100	11.0
Exterior Sheathing and Siding	100	8.6
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	3	0.6
Misc.: Stairs, Fireplace, Paint, Trim	100	12.0
TOTAL		81.6

Fig. 3-3. House Damage Summary, House No. 1-2



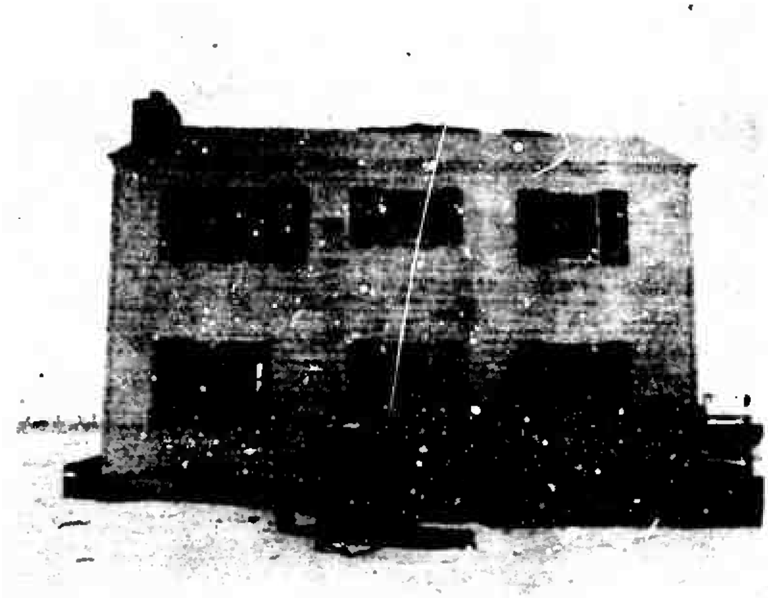
Peak Overpressure (psi) 4.0
Charge Size (kt) 30.0

Positive Phase Impulse (psi-msec) ~ 1630
Ground Range (ft) 5500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	20	3.4
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	8	1.3
Interior Plaster	30	3.3
Exterior Sheathing and Siding	25	2.2
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	75	9.0
TOTAL		35.6

Fig. 3-4. House Damage Summary, House No. I-3



Peak Overpressure (psi) 2.6 Positive Phase Impulse (psi-msec) ~ 1150
Charge Size (kt) 30.0 Ground Range (ft) 7800

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	33	2.3
Exterior and Interior Wall Framing	4	0.6
Interior Plaster	30	3.3
Exterior Sheathing and Siding	9	0.8
Doors	50	2.3
Windows	100	4.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	30	3.6
TOTAL		17.7

Fig. 3-5. House Damage Summary, House No. I-4

Peak Overpressure (psi) 1.3
Charge Size (lb) 10,000

Positive Phase Impulse (psi-msec) ~ 47
Ground Range (ft) 865

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	1	0.1
Exterior and Interior Wall Framing	0	0
Interior Plaster	6	0.7
Exterior Sheathing and Siding	0	0
Doors	20	0.9
Windows	44	2.1
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	12	1.4
TOTAL		5.2

Fig. 3-6. House Damage Summary, House No. I-5

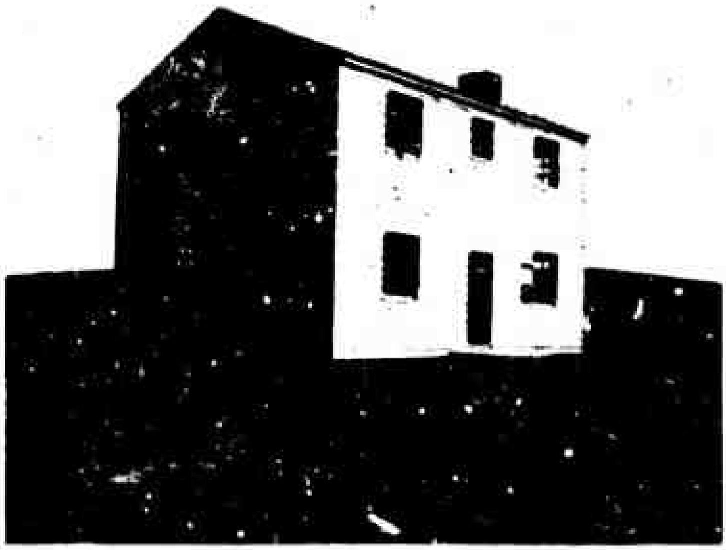
Peak Overpressure (psi) 1.2
Charge Size (lb) 10,000

Positive Phase Impulse (psi-msec) ~ 44
Ground Range (ft) 865

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	3	0.2
Exterior and Interior Wall Framing	0	0
Interior Plaster	6	0.7
Exterior Sheathing and Siding	0	0
Doors	20	0.9
Windows	61	2.9
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	15	1.8
TOTAL		6.5

Fig. 3-7. House Damage Summary, House No. I-6

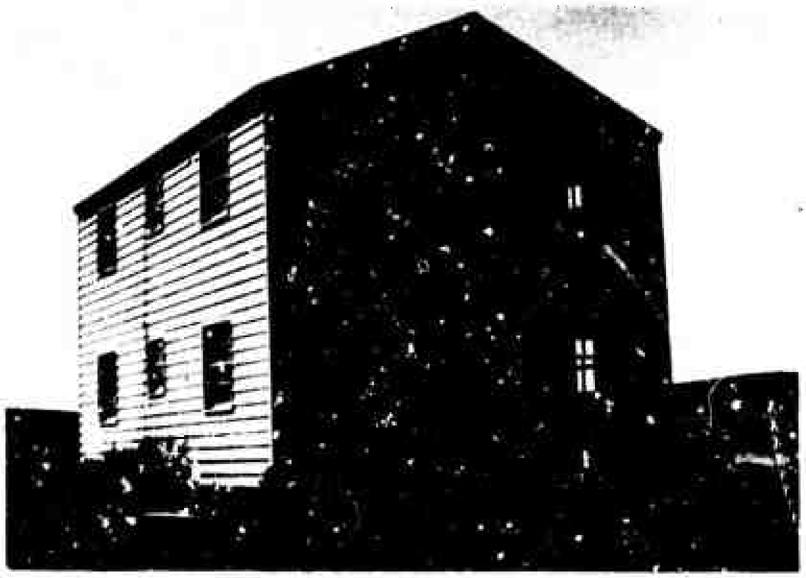


Peak Overpressure (psi) 1.1 Positive Phase Impulse (psi-msec) ~ 185
Charge Size (ton) 500 Ground Range (ft) 4000

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	14	1.0
Exterior and Interior Wall Framing	3	0.5
Interior Plaster	5	0.6
Exterior Sheathing and Siding	0	0
Doors	18	0.8
Windows	47	2.3
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	3	0.4
TOTAL		5.6

Fig. 3-8. House Damage Summary, House No. I-7



Peak Overpressure (psi) 1.6 Positive Phase Impulse (psi-msec) ~ 161
Charge Size (ton) 100 Ground Range (ft) 1660

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	27	1.9
Exterior and Interior Wall Framing	7	1.1
Interior Plaster	25	2.8
Exterior Sheathing and Siding	2	0.2
Doors	17	0.8
Windows	55	2.6
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	12	1.4
TOTAL		10.8

Fig. 3-9. House Damage Summary, House No. I-8

Peak Overpressure (psi) 2.7
Charge Size (ton) 500

Positive Phase Impulse (psi-msec) ~ 340
Ground Range (ft) 2256

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	60	4.2
Exterior and Interior Wall Framing	23	3.7
Interior Plaster	40	4.4
Exterior Sheathing and Siding	20	1.7
Doors	67	3.1
Windows	93	4.5
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	30	3.6
TOTAL		25.2

Fig. 3-10. House Damage Summary, House No. I-9

Section 4

TYPE II HOUSE TESTS

INTRODUCTION

The typical Type II House is a conventional center hall, two-story, house with 8-in. load bearing masonry walls, consisting of an outer wythe of brick and a backup wythe of cinder block. The house is 33 ft 4 in. long by 24 ft 8 in. wide with a full basement and a gabled roof (see Fig. 4-1). There were four rooms on each floor and a brick fireplace in the living room. As in the case of the Type I House the walls were plastered, and the finish coat and plumbing, heating, and electrical systems were omitted to reduce the cost.

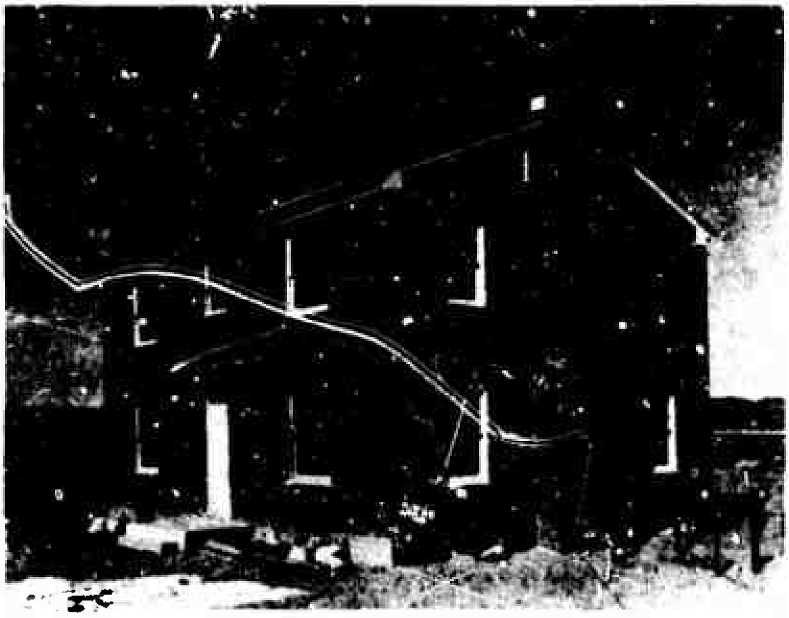
TEST DESCRIPTION

The data from two Type II House tests are included in this paper. These Houses (nos. II-1 and II-2) were exposed to the air blast from the 30 kt (Apple II) nuclear device during Operation TEAPOT.

House II-1 was located at a ground range of 10,500 ft where the peak incident overpressure was 1.7 psi; House II-2 was located at 4700 ft where the peak incident overpressure was 5.1 psi.

Post-test photos and damage estimates for these two tests are presented in Figs. 4-2 and 4-3.

Fig. 1-1. Photographs of Type II House



Peak Overpressure (psi) 1.7   Positive Phase Impulse (psi-msec) ~ 840
Charge Size (kt) 30.0   Ground Range (ft) 10,500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	12	2.0
Roof Framing and Roof Surface	30	2.1
Exterior and Interior Wall Framing	0	0
Interior Plaster	15	1.7
Exterior Sheathing and Siding	0	0
Doors	17	0.8
Windows	80	3.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	4	0.5
TOTAL		10.9

Fig. 4-2. House Damage Summary, House No. II-1

Peak Overpressure (psi) 5.1
Charge Size (kt) 30.0

Positive Phase Impulse (psi-msec) ~ 1850
Ground Range (ft) 4700

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	100	17.0
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	100	16.0
Interior Plaster	100	11.0
Exterior Sheathing and Siding	100	8.6
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	2	0.4
Misc.: Stairs, Fireplace, Paint, Trim	100	12.0
TOTAL		81.4

Fig. 4-3. House Damage Summary, House No. II-2

Section 5

TYPE III HOUSE TESTS

CONSTRUCTION DETAILS

Type III Houses are one-story, wood-frame, ranch-style houses. They were constructed on a poured-in-place concrete slab at grade, and were of conventional design with the exception of the bathroom, which was designed as an above-ground shelter with 8-in.-thick reinforced concrete walls and ceiling. Pre-shot photographs are presented in Fig. 5-1.

TEST DESCRIPTION

Two Type III Houses were exposed to the air blast from the 30 kt Apple II nuclear device during Operation TEAPOT. One of the Houses (no. III-1) was located 10,500 ft from ground zero at a peak incident overpressure of 1.9 psi; the second House (no. III-2) was located 4700 ft from ground zero at a peak incident overpressure of 5.1 psi.

Post-test photographs and damage estimates for these tests are presented in Figs. 5-2 and 5-3.

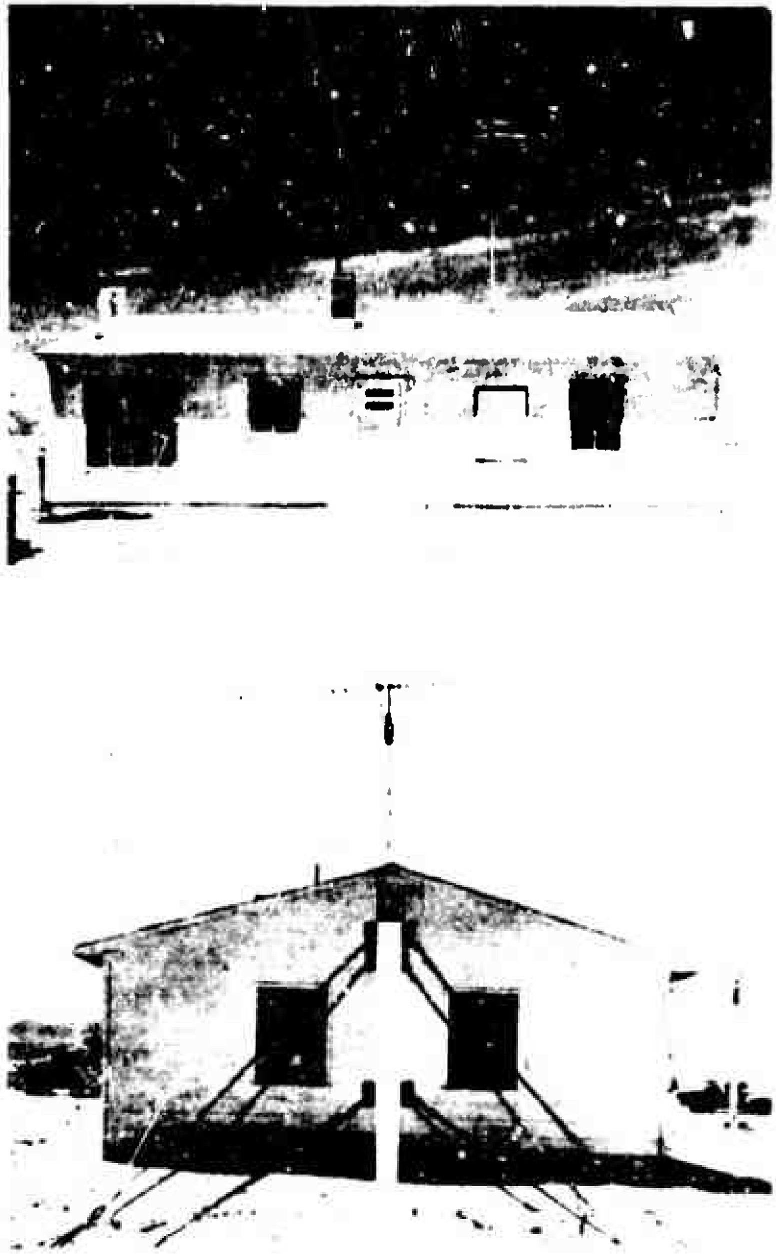


Fig. 5-1. Photographs of Type III House

Peak Overpressure (psi) 1.9 Positive Phase Impulse (psi-msec) ~ 840
Charge Size (kt) 30.0 Ground Range (ft) 10,500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	10	0.7
Exterior and Interior Wall Framing	10	1.6
Interior Plaster	30	3.3
Exterior Sheathing and Siding	0	0
Doors	10	0.5
Windows	80	3.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	15	1.8
TOTAL		11.7

Fig. 5-2. House Damage Summary, House No. III-1

Peak Overpressure (psi) 5.1
Charge Size (kt) 30.0

Positive Phase Impulse (psi-msec) ~ 1850
Ground Range (ft) 4700

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	100	17.0
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	100	16.0
Interior Plaster	100	11.0
Exterior Sheathing and Siding	100	8.6
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	3	0.6
Misc.: Stairs, Fireplace, Paint, Trim	100	12.0
TOTAL		81.6

Fig. 5-3. House Damage Summary, House No. III-2

Section 6

TYPE IV HOUSE TESTS

CONSTRUCTION DETAILS

The Type IV Houses were two-story brick structures with load-bearing walls. These structures were approximately 40- by 30- by 36-ft high and are representative of urban construction found in many citiea in Europe. These atructures had metal roofs, wood rafters, and wood floor joists, with the interior partitions which supported the ceiling and floor joista of bearing wall maaonry construction (see Fig. 6-1). The structures were oriented face-on to the blast since the heavy masonry bearing walls constitute shear walls which make the structures less vulnerable in thia direction.

TEST DESCRIPTION

Two Type IV Housea were exposed to the air blaat from a 50 kt nuclear device during Operation GREENHOUSE, conducted at Entwetok Atoll in the Pacific. One of the Houses (no. IV-1) was located 7020 ft from ground zero at a peak incident overpressure of 3.6 pai. The aecond Houae (no. IV-2) was located 4245 ft from ground zero at a peak incident overpreasure of 8.6 pai.

Post-test photos and damage eatimates for these tests are preaented in Figs. 6-2 and 6-3.

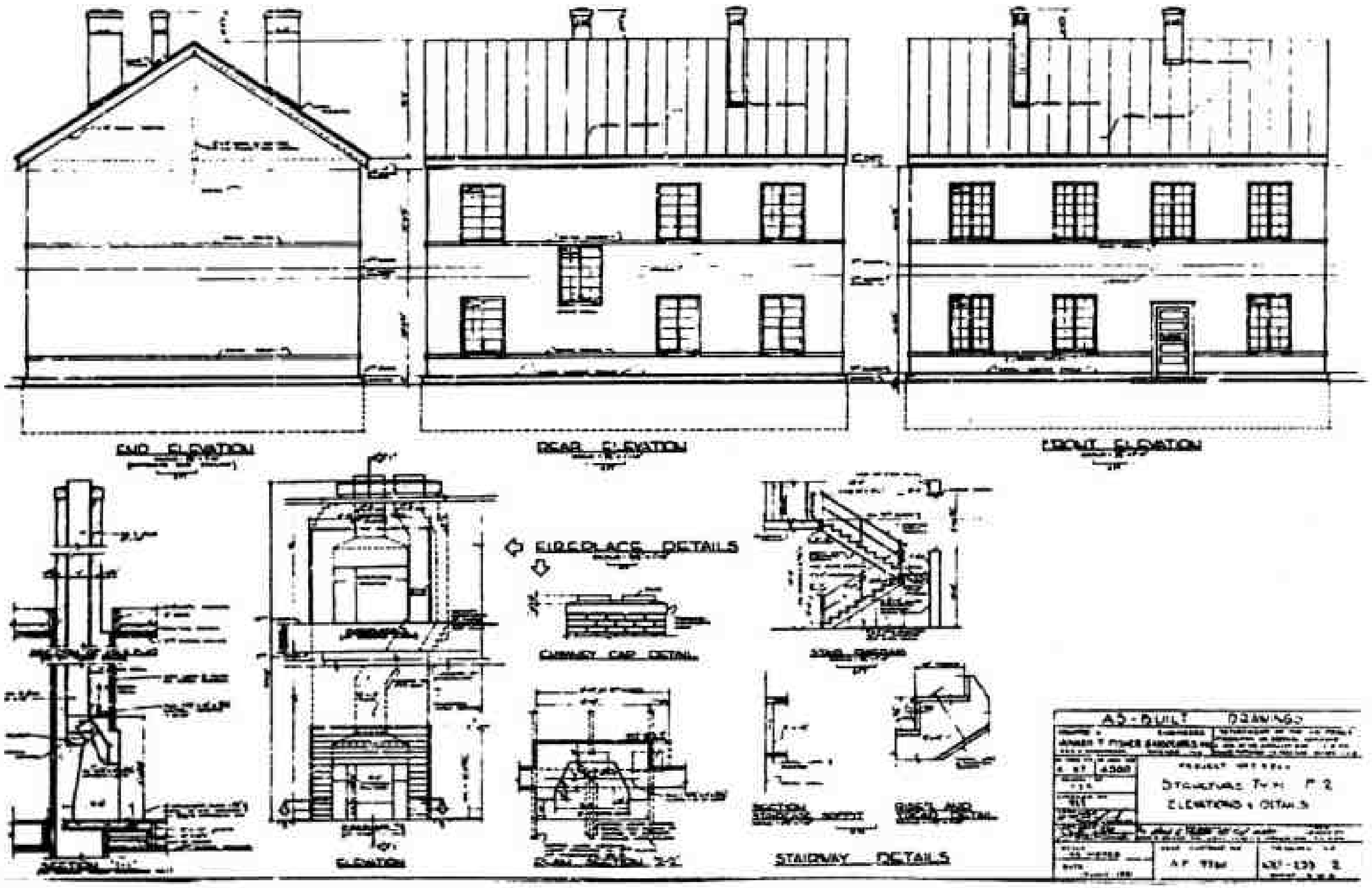
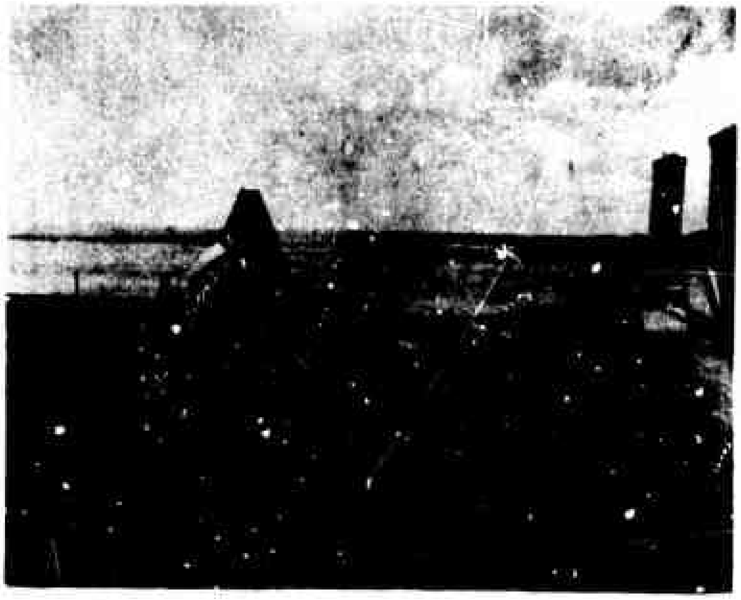


Fig. 6-1. Construction Drawing — Type IV House



Peak Overpressure (psi) 3.6
Positive Phase Impulse (psi-msec) ~ 520
Charge Size (kt) 50.0
Ground Range (ft) 7020

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	10	1.7
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	20	3.2
Interior Plaster	20	2.2
Exterior Sheathing and Siding	10	0.9
Doors	25	1.2
Windows	80	3.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	25	3.0
TOTAL		23.0

Fig. 6-2. House Damage Summary, Houae No. IV-1

Peak Overpressure (psi) 8.6   Positive Phase Impulse (psi-msec) ~ 92[illegible]
Charge Size (kt) 50.0   Ground Range (ft) 4245

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	60	10.2
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	50	8.0
Interior Plaster	60	6.6
Exterior Sheathing and Siding	50	4.3
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	10	1.9
Misc.: Stairs, Fireplace, Paint, Trim	50	6.0
TOTAL		53.4

Fig. 6-3. House Damage Summary, House No. IV-2

Section 7

DAMAGE CORRELATION

The data from Figs. 3-2 through 3-10, 4-2 and 4-3, 5-2 and 5-3, 6-2 and 6-3 are summarized in Table 7-1. It is clear from inspection that the percent damage data correlates very poorly with positive phase impulse. Referring to Type I Houses alone, Houses I-7 and I-10 experienced identical levels of damage (6 percent) although the incident positive phase impulses differed by almost a factor of 7 (185 psi-msec compared with 26 psi-msec). Similarly, if all wood frame houses are considered, Houses I-8 and III-1 experienced almost the same amount of damage (11 and 12 percent respectively) although incident positive phase impulse differed by more than a factor of 5 (161 psi-msec compared with 840 psi-msec).

On the other hand, damage appears to correlate reasonably well with either overpressure or scaled ground range ($D/W^{1/3}$). This is borne out by Figs. 7-1 and 7-2. In both figures there appears to be little difference in response for Type I, II or III Houses. That is, one- and two-story ordinary (unstrengthened) wood frame houses and two story masonry houses (without shear walls) appeared to behave essentially the same. Strengthened wood frame houses and houses with heavy shear walls received significantly less damage.

One important aspect of the good correlation of damage with either incident overpressure or scaled ground range is that it implies that damage to these types of structures tends <u>not</u> to be yield dependent. Referring again to Houses I-8 and III-1 (or II-1), the former was exposed to blast from the equivalent of about <u>100 tons</u> of TNT, the latter to blast from the equivalent of about <u>30,000 tons</u> of TNT, a difference by a factor of 300. Yet damage levels, overpressure levels, and scaled ground ranges are all reasonably close. Similarly, Houses I-7 and I-10 were exposed to blast from explosive charges that differed in size by a factor of almost 400 (1,000,000 lb compared with 2,550 lb) yet damage levels and overpressure levels were identical, and scaled ground ranges were very close (40.0 versus 38.7).

Table 7-1

SUMMARY OF HOUSE DAMAGE

TEST NO.	CHARGE SIZE	GROUND RANGE (ft)	$D/W^{1/3}$* ($ft/lb^{1/3}$)	PEAK OVERPRESSURE (psi)	APPROXIMATE POSITIVE PHASE IMPULSE (psi-msec)	DAMAGE QUANTITY (percent)
			TYPE I HOUSE			
I-1	16.2 kt	7500	29.6	1.8	900	14
I-2	16.2 kt	3500	13.8	5.0	1750	82
I-3	30.0 kt	5500	17.7	4.0	1630	36
I-4	30.0 kt	7800	25.1	2.6	1150	18
I-5	10,000 lb TNT	865	40.2	1.3	47	5
I-6	10,000 lb TNT	865	40.2	1.2	44	7
I-7	500 ton TNT	4000	40.0	1.1	185	6
I-8	100 ton AN/FO**	1660	28.4	1.6	161	11
I-9	500 ton TNT	2256	22.7	2.7	340	25
			TYPE II HOUSE			
II-1	30.0 kt	10,500	33.9	1.7	840	11
II-2	30.0 kt	4700	15.2	5.1	1850	81
			TYPE III HOUSE			
III-1	30.0 kt	10,500	33.9	1.9	840	12
III-2	30.0 kt	4700	15.2	5.1	1850	82
			TYPE IV HOUSE			
IV-1	50.0 kt	7020	19.1	3.6	520	23
IV-2	50.0 kt	4245	11.5	8.6	920	53

* Scaling for nuclear bursts assumes 50 percent nuclear-to-TNT efficiency, i.e., 1 kt nuclear is equivalent to 1×10^6 lb TNT.

** Assumed equivalent to TNT.

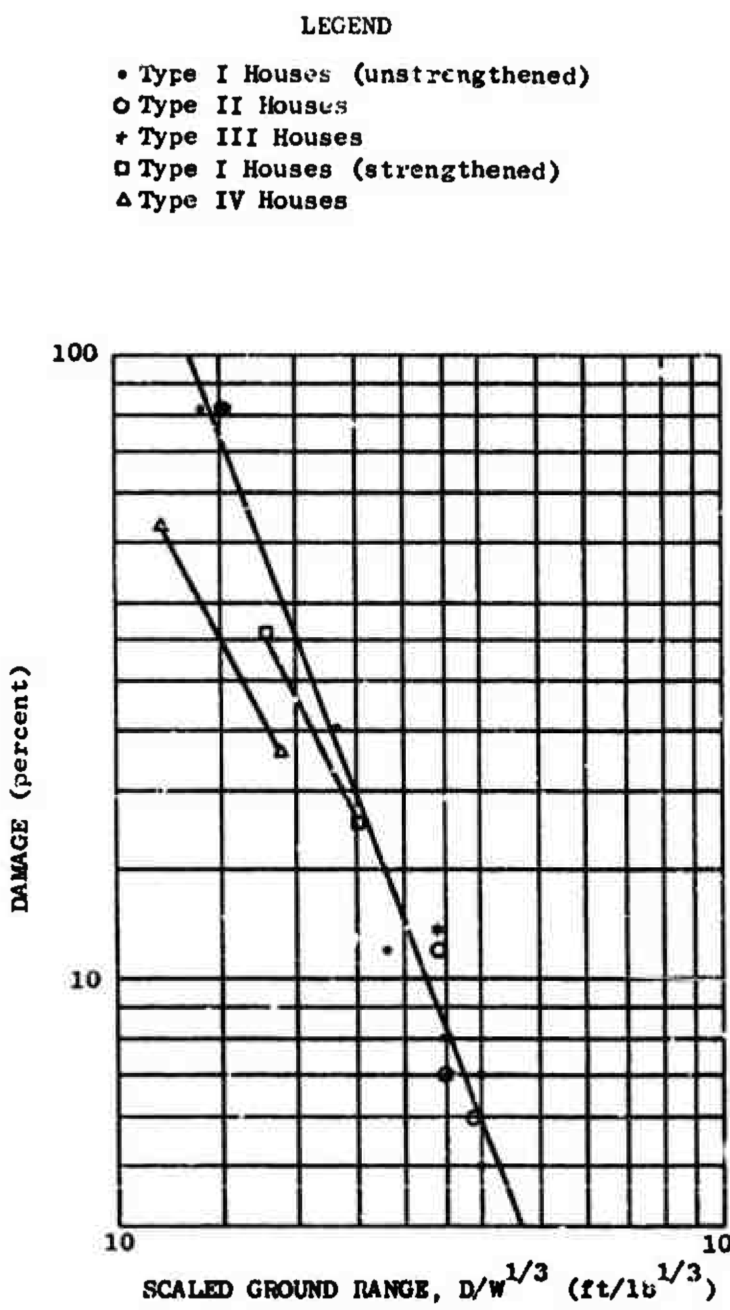


Fig. 7-1. Percent Damage vs Scaled Ground Range

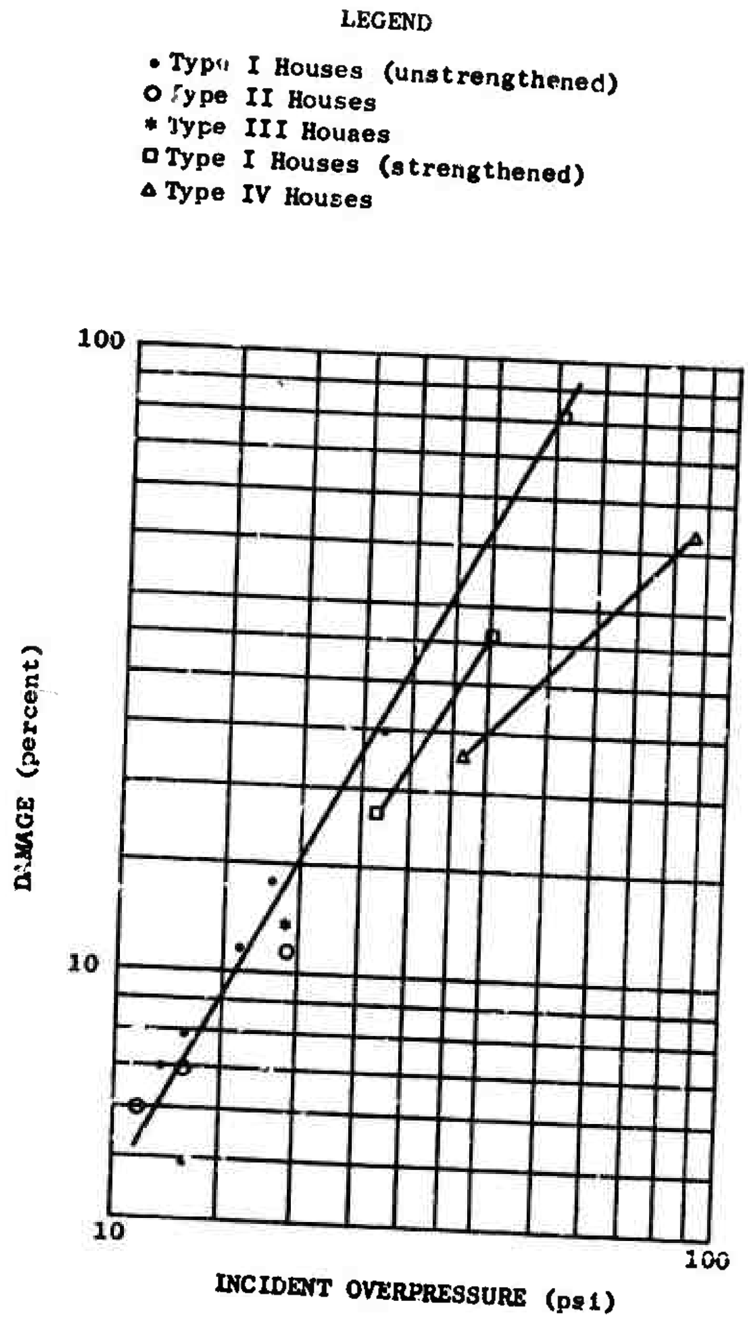


Fig. 7-2. Percent Damage vs Incident Overpressure (psi)

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HOUSE NO.	REFERENCE
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Houses I-3 and I-4	Randall, Philip A., Damage to Conventional and Special Types of Residences Exposed to Nuclear Effects, WT-1194, Office of Civil and Defense Mobilization, Federal Housing Administration, and Housing and Home Finance Agency, Washington, D.C., March 1961.
Houses I-5 and I-6	Wilton, Chuck, Evaluation of Explosives Simultaneity Tests, NWC TP 4720, Naval Weapons Center, China Lake, California, May 1969.
House I-7	Dickinson, A.A., and A.R. Sound, Blast Effects on Residential Dwellings, WT-2117, Naval Weapons Center, China Lake, California, March 1971.
Houses I-8 and I-9	Wilton, Chuck, Assessments of House Damage from Event Dial Pack and 100 ton AN/FO Test, DNA 2729I, Defense Nuclear Agency, Washington, D.C., March 1972.
Houses II-1 and II-2	Refer to WT-1194 above.
Houses III-1 and III-2	Refer to WT-1194 above.
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COMPUTER PROGRAM FOR PREDICTING THE SAFETY OF PEOPLE IN A DIRECT EFFECTS NUCLEAR WEAPON ENVIRONMENT

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INTRODUCTION

This paper describes a computer simulation model (program) which was developed for the purpose of predicting the survivability (relative safety) of people located in conventional buildings when subjected to the direct effects of nuclear weapons. This analytic tool was developed as part of a study which is supported by Defense Civil Preparedness Agency (DCPA) formerly Office of Civil Defense. The paper discusses the formulation of this computer program, its physical basis and usage. Some representative results are illustrated by means of example problems.

STUDY EMPHASIS

The primary emphasis of the study (Ref. 1) which resulted in the formulation of this computer program is on conventional buildings and especially on those which contain substantial numbers of people for significant portions of the day. The reason is that conventional buildings constitute the only significant, current sheltering resource. Each of them has some level of inherent ability in providing protection, not only against the effects of nuclear weapons, but also against natural disasters such as earthquakes, tornados, and hurricanes. It is therefore important to have a firm grasp of their protective capabilities. Although much of the methodology developed in this study is applicable to evaluating the sheltering potential of buildings against natural hazards, the current emphasis is on the direct effects which occur in the Mach region of nuclear weapons.

The ultimate usage of results is to provide for reliable on-site assistance at the local civil defense level. The results

of the study would take the form of a concise building classification scheme which would be used for the rating of buildings in terms of their inherent protective capabilities and thus for the optimum distribution of the local population within them before and after the event. It is also capable of performing damage assessment studies and should be used by persons engaged in such work.

The current study considers only the direct (prompt) effects. These effects and corresponding casualty-producing mechanisms are listed in Table 1 in the order of the event. The correspondence between effects and casualty-producing mechanisms is for the most part self-explanatory. The manner in which they are treated in the analytic process is discussed in the following section.

Table 1

EFFECTS AND CASUALTY-PRODUCING MECHANISMS

1. Thermal Radiation	→ Burn Casualty	
2. Prompt Nuclear Radiation	→ Radiation Casualty	
3. Primary Blast	→ Blast Casualty (Pulmonary Hemorrhage)	
4. Secondary Blast:		
• Translation	→ Impact Casualty	→ Head Whole Body
• Debris (Blunt, Penetrating)	→ Impact Casualty	→ Head Thorax Abdomen Limbs
• Acceleration		Whole Body

The influence of fires which may occur subsequent to prompt effects is not considered in the computer simulation. In a fire environment casualties can arise as a result of flame exposure, smoke, toxic gases and temperature gradients. The task of evaluating the sheltering potential of buildings against blast induced fire effects is significantly different from that of prompt effects and requires the results of a prompt effects analysis. For a given attack condition the occurrence, distribution and intensity of fires is dependent on the fire load

and the manner in which the ignited pieces become distributed and intermixed among the resulting debris piles. It also depends on secondary contributions such as the existence of heating fuels, broken gas lines, etc. Further, the extent to which a given fire is capable of producing casualties in a building depends on the ability of its occupants in mitigating its effects, i.e., putting it out, reducing its intensity by removing debris, evacuating the building, etc. The formulation of the fire problem for the purpose of evaluating the sheltering potential of buildings is being considered in another study (Ref.2).

The degree to which a given building can provide protection depends on the particular weapon environment, structural characteristics of subject building, types and distribution of buildings in the neighborhood and dispersal of the population.

Building types are numerous and if considered from an architectural vantage point, the class of possible building concepts is for all practical purposes unlimited. Buildings may be single- or multistory and may or may not contain basements. Structural systems may be framed, load-bearing or a combination. A framing system may be of wood, reinforced concrete or steel. Walls may be structural or nonstructural and may consist of brick, tile, reinforced concrete, steel, wood, glass, etc. Floor systems may be of the wood joist type, tile arch, composite deck or concrete. If made of concrete the floor system may consist of one-way slabs, two-way slabs, flat plate, flat slab, waffle slab, etc. Different combinations of these characteristics in a given building result in different levels of protection.

Since the class of existing buildings is very broad, the task of developing a reliable scheme for classifying them in terms of their protective capabilities must necessarily consider an adequately large and representative sample. Since individual buildings are generally complex, the task also requires an analytic procedure which is capable of analyzing each individual building in sufficient detail.

The computer simulation model developed in the course of this study is briefly described in the following section. It is a deterministic procedure which is capable of considering buildings in substantial detail and of predicting the relative safety of people located within when subjected to nuclear weapon environments. The detailed formulation allows the user to consider many categories of data (weapon environment, building characteristics, disposition and dispersion of personnel, etc.) and to determine the relative importance of each variation on the inherent safety.

COMPUTER SIMULATION MODEL

This computer simulation model is entitled BAP* code. It is a FORTRAN IV computer program currently operational on the UNIVAC 1108 computer. It is a modular program and consists of the following parts.

1. Input: The input routine accepts data on the weapon size, height of burst and range from ground zero. Building description is input in terms of geometry and physical properties. This includes data on window sizes, sill heights, type of window covering, failure overpressure levels for exterior and interior walls, debris size distributions, etc. The program also requires data on personnel, i.e., where they are located and in what initial bodily positions -- prone or standing. Basements and upper stories are treated separately.

2. Weapon Effects Generator: Pertinent weapon effects data are contained within the computer program. For a given weapon size, height of burst and range from ground zero this routine generates time-dependent intensities of specified free-field weapon effects at the location of building being analyzed.

*Acronym for Building Analysis Program

3. <u>Dose Prediction Routines</u>: This set of routines determines the intensities of individual effects and casualty mechanisms that are experienced by personnel in subject building.

- Thermal Radiation -- This routine modifies the intensity of free-field thermal energy for each room facing the direction of blast by the presence of window glass, curtains, window sills, neighboring buildings, etc. Resulting intensities are applied uniformly to the room occupants.
- Prompt Nuclear Radiation -- This routine modifies the intensity of free-field nuclear radiation for each room by the use of building mass and geometry. Resulting intensities are applied uniformly to room occupants.
- Blast Filling -- By making use of building geometry, sizes of window openings, room geometries, failure overpressure levels for exterior and interior walls, this routine determines the time dependent dynamic pressure intensities at several locations within each room analyzed.
- Blast Translation and Impact Routine -- Using the loading determined in the blast filling routine, this routine applies it to simulated personnel located in respective rooms to determine the type and intensity of impact velocities. This routine uses a two-dimensional articulated man as an analysis model. Impacts can be on the floor, walls or on the ground surface. It may be a head or a whole body impact.
- Debris -- This routine makes use of a free-flight rigid body (debris) model to determine types and intensity of debris impact on personnel. Only structural debris as occurs from the break of walls is considered.

4. <u>Casualty Estimation Routines</u>: A routine is provided to relate each of the computed dose intensities to corresponding casualty criteria. These criteria are contained within the program and are described as follows.

- Thermal Radiation -- The thermal pulse producing second and third degree burns resulting from direct exposure of the skin, reradiation and ignition of clothing and subsequent burning of the skin is considered. The probability of mortality is then related to percent of body area burned (see Ref. 3).

- Prompt Nuclear Radiation-- Radiation casualties from initial gamma and neutron radiation are determined by extrapolating animal data based upon Hiroshima and Nagasaki results. The mean lethal (i.e., 50 percent probability of mortality) dose was estimated at 500 REM (see Refs. 4,5,6 and 7).
- Primary Blast-- Blast casualties due to pulmonary hemorrhage are based on data collected from animal experiments and extrapolated by weight of species. This resulted in an estimated mean lethal overpressure of 75 psi for man (see Refs. 8,9,10,11, 12 and 21).
- Blast Translation-- Translation of people in the blast winds can cause casualties with resulting impacts on hard surfaces. Impact data from animal experiments, related human free fall accident experience, and skull impact experiments resulted in mean lethal velocities for two types of impacts: head and whole body (see Refs. 13, 14 and 15). The mean lethal velocities for man are estimated at 18 ft/sec for head impact and 54.4 ft/sec for whole body impact.
- Debris --Blast generated debris from building walls and contents accelerated by the blast winds may cause casualties. Three debris mechanisms were identified (see Ref. 21): impulse loading related to debris momentum (MV); crushing or tearing related to debris energy (MV^2); and cutting or penetration related to energy times the square of the velocity (MV^4). Wound data for human cadavers and animals were reviewed (see Refs. 16,17,18,19 and 20) and casualty criteria developed as function of mass and velocity of the debris particles.
- Acceleration-- Persons in direct line of the blast jet as it enters a building are subject to possibly harmful accelerations without translation. The mean lethal dynamic pressure (q) as related to acceleration casualties is estimated at 8.7 psi (see Refs. 22 and 23).

The model, after considering the above effects in context of given building parameters, arrives at probabilities of mortality for each effect for the building occupants. Combination of the separate effects results in one survivability estimate for the building. This estimate is for building occupants located throughout the structure; estimates for people located in specific areas within the building may also be made. A basic flow chart of the process is shown as Figure 1.

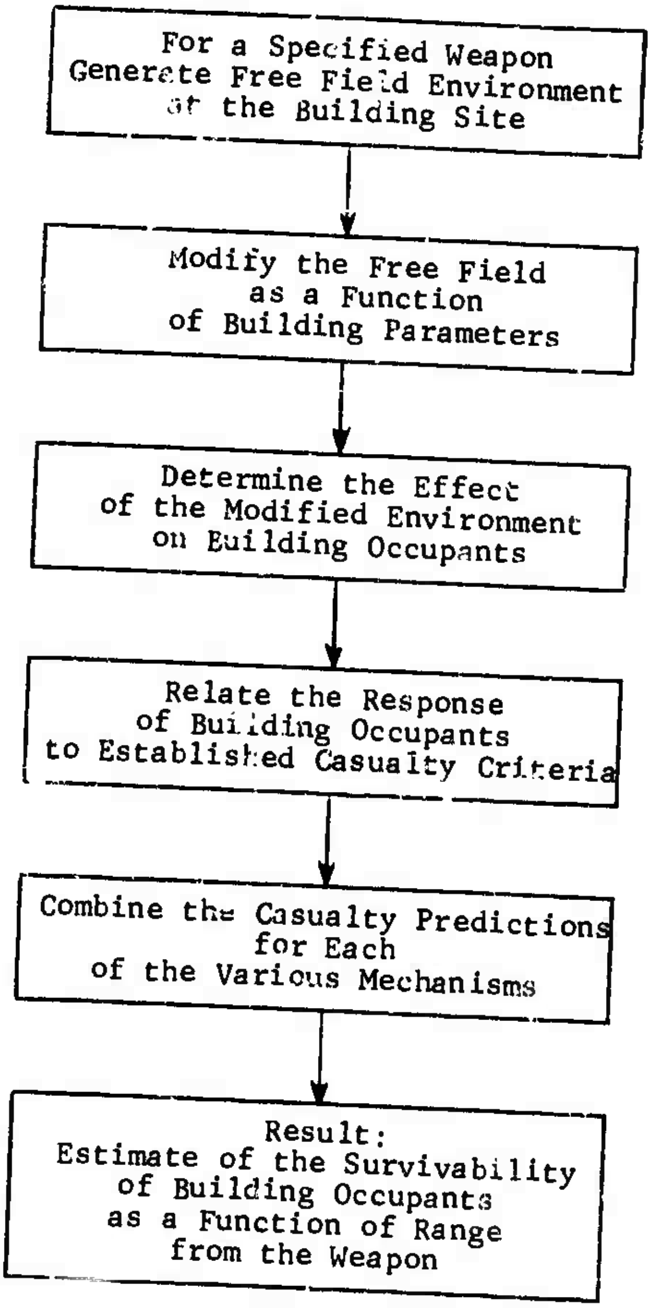


Figure 1 General Computational Process

SAMPLE RESULTS

To illustrate more clearly the operation of this simulation model, the operation of several routines is described in terms of typical results. Figure 2a shows a portion of a framed multistory building and a selected standing occupant. The configuration is typical of the type of buildings that can be treated by this computer program. This illustration indicates some of the possible effects of blast loading that are considered by the model, i.e., blast filling of interior rooms, collapse of walls and translation of building occupants. Figure 2b shows the loading that would be experienced by an occupant located as shown in Figure 2a. It consists of two parts. In the diffraction phase the occupant experiences a sudden pulse whose magnitude and duration depend on the free-field, building geometry, window opening, room geometry, and the geometry of the occupant. This pulse tends to move the occupant in the direction away from the window. This is followed by a sharp negative load (opposite direction) produced by the reflection of the wave off the back wall. The duration of these pulses is on the order of several milliseconds. In the drag phase the occupant is subjected to a dynamic pressure loading whose duration depends on the extent to which venting channels are created by the collapse of head-on walls. In the model the loading described is expressed in terms of lift and drag forces whose magnitudes depend on specific aerodynamic coefficients and the orientation of the occupant.

A typical translation result is shown in Figure 3 which illustrates the trajectory of an occupant modeled as a rigid block. The direction of blast is to the right and the occupant faces away from the direction of blast. He rotates, impacts on the head and comes to rest at a wall located 60 ft from his original position. The record of impact velocities during the motion is compared with established fatality criteria to arrive at a survivability estimate.

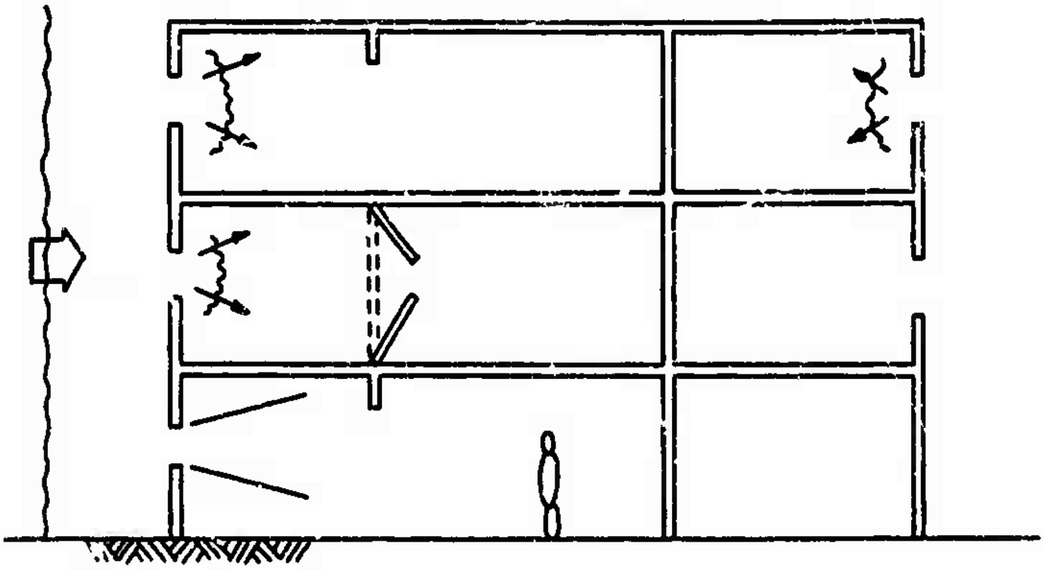


Figure 2a Representative Building with Occupant

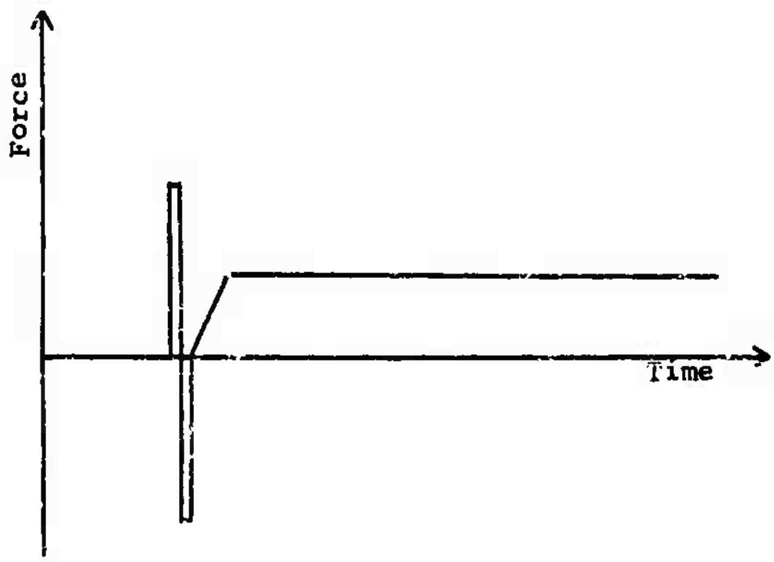
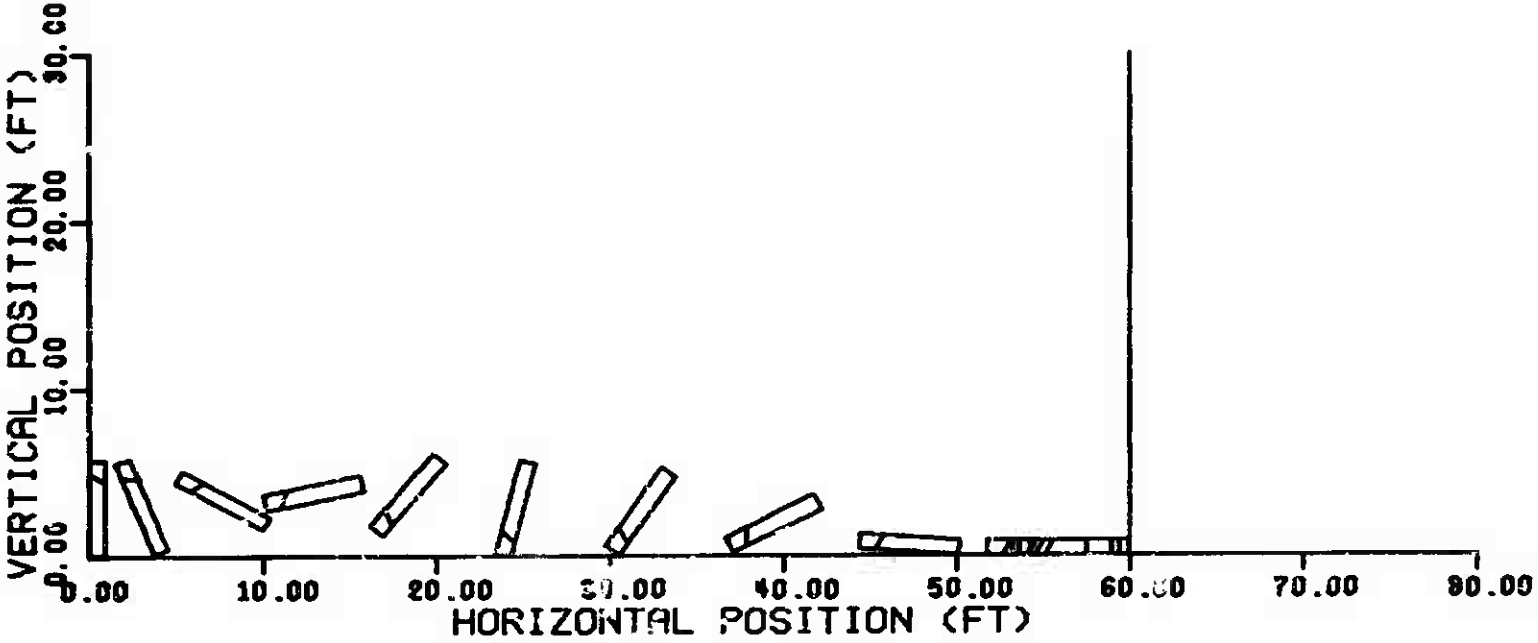


Figure 2b Idealized Loading on Selected Building Occupant



RUN 18: 8.0 PSI BLAST TRAJECTORY OF MAN: $\Delta T=0.10$ SEC

Figure 3 Sample Trajectory Plot

The rigid block model described has been replaced by one which treats the occupant as an articulated man with joints at the neck and hips. The joints are modeled by means of springs and dashpots. Some results are shown in Figure 4. Of special interest is the lower case in which an initial impact of 10 ft/sec on the shoulders is followed by a 21 ft/sec head impact, nearly 100 percent fatal. The original rigid block model would have predicted a single head impact of approximately 14 ft/sec, barely fatal.

Application of blast loading on the building walls may result in their collapse, depending on their makeup and support conditions. Resulting debris has a definite effect on survivability of occupants. Figure 5 shows some typical debris results for a portion of a building whose exterior and interior walls collapse at an overpressure $p_b = 1$ psi and whose front wall has 40 percent windows ($\overline{A} = 40\%$). Results are for the two rooms shown in Figure 5 and for the condition that occupants are uniformly distributed (standing) over the floor area at 10 sq ft per occupant. The figure shows the variation in survivability with free-field overpressure for two fragment sizes. In one case the wall is assumed to break up in 1 in. fragments, in the other it is assumed to break up in 16-in. fragments. In actual operational studies a range of fragment sizes based on experimental results are used.

Survivability to blast pressure, acceleration, thermal and prompt nuclear radiation is determined for the occupants of the structure and all of the results combined to arrive at a total survivability estimate. Figure 6 shows average, combined results for an actual building analyzed for DCPA in the current study.

Results, such as those described above, provide a clearer insight into the protective capabilities of buildings and help to eliminate some of the misconceptions which existed in the past. One common mistake which has been made in the past was to relate the overall strength of a building to its ability in providing protection.

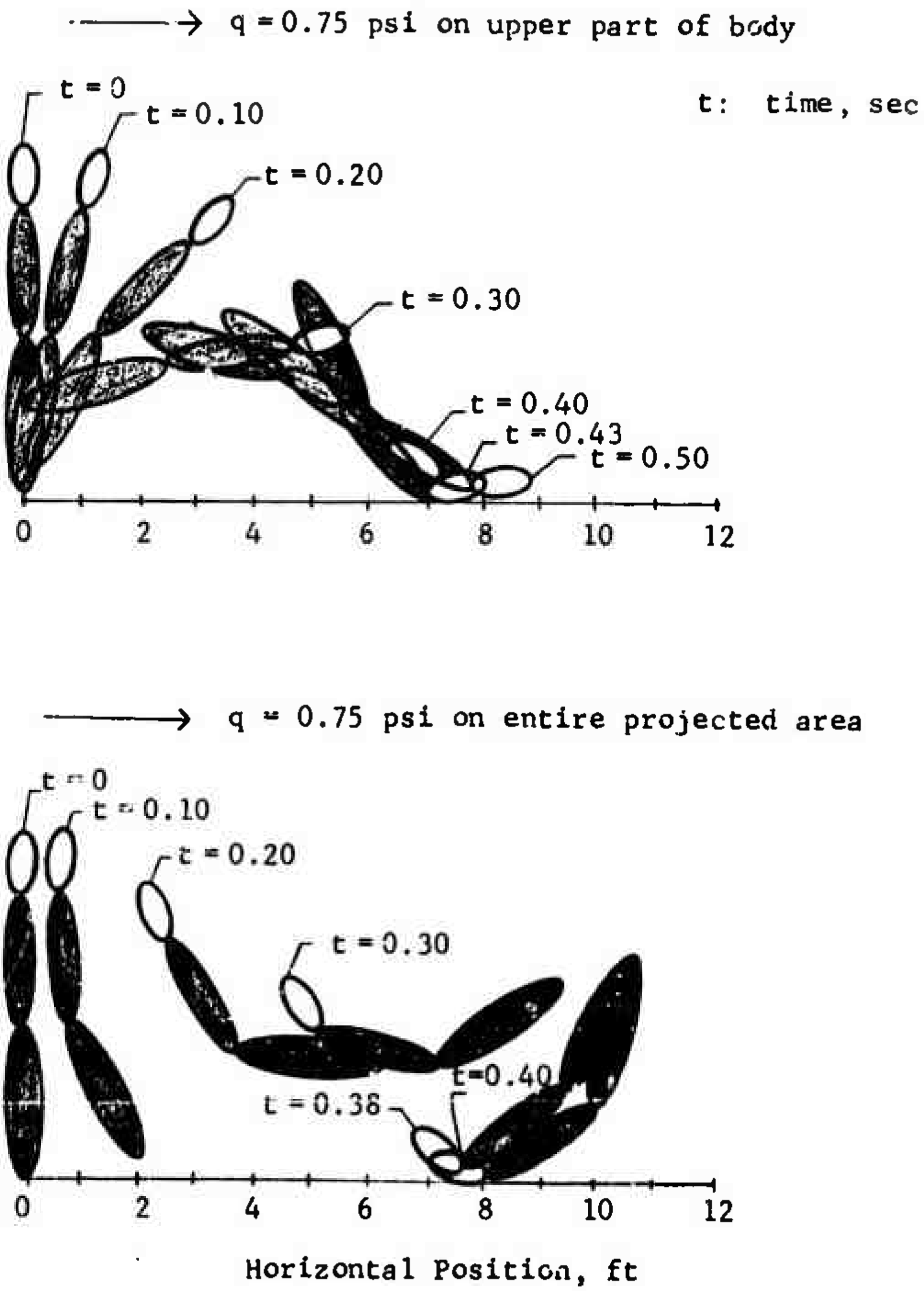


Figure 4 Articulated Man Model

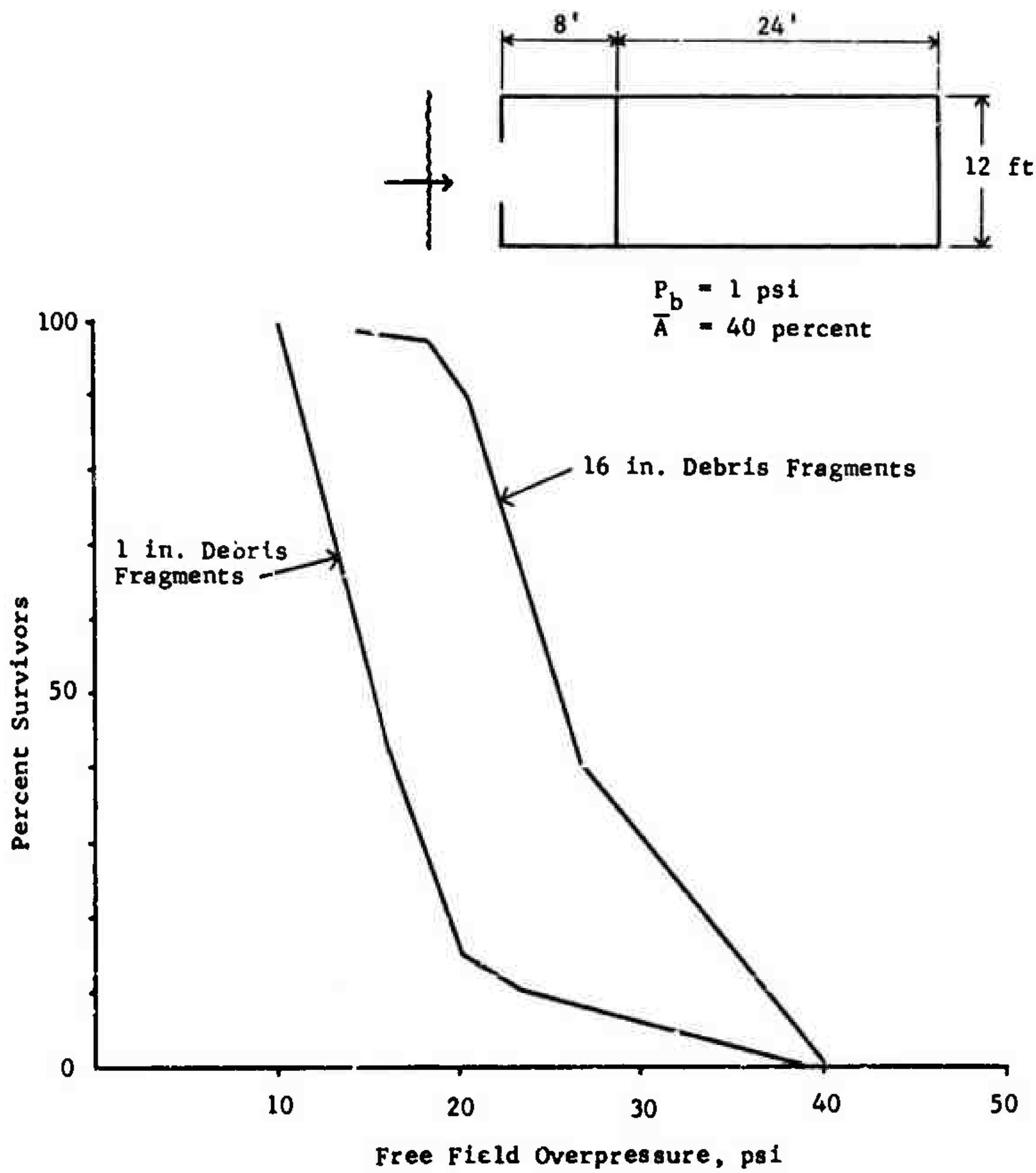


Figure 5 Typical Debris Effects

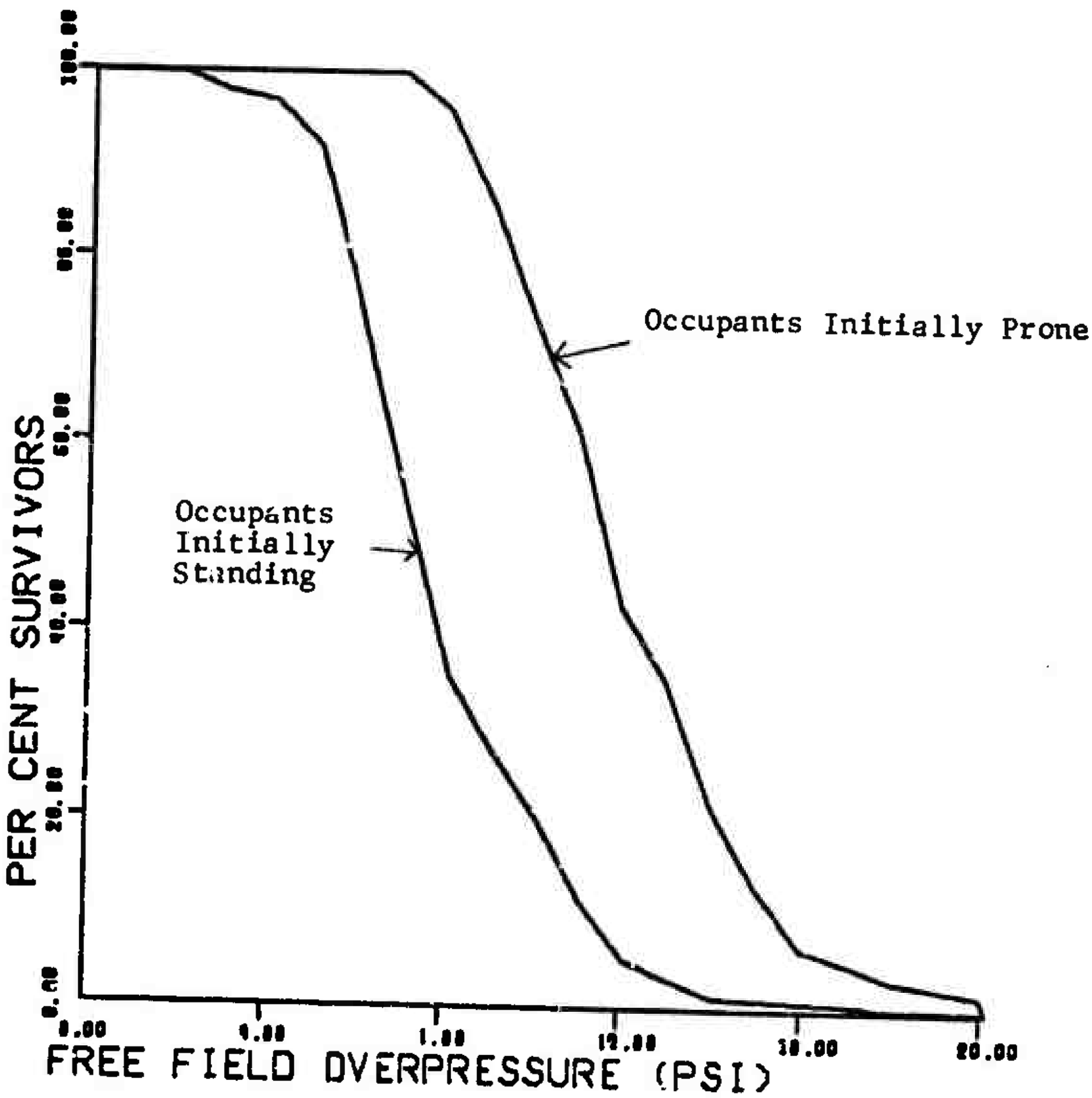


Figure 6 Survivability Results (All Effects Shelter Survey Building No. 33)

Such correspondence does not hold in general, especially in the case of framed buildings. Consider a reinforced concrete framed, multistory office building whose exterior cladding consists almost entirely of glass, i.e., many large windows. Such buildings are currently quite common. At the range of 5 psi from an MT size weapon the probability is 90 percent that at least half of the poeple located in upper stories (from the 4th story and up) will be fatalities as a result of being blown out of the building. The building itself would lose its windows; its partitions would be severely damaged as would its mechanical and electrical systems. The structure itself, however, would remain standing at this and higher overpressures. For this example (others can be cited) the resistance of the basic structure is not directly proportional to inherent safety.

DISCUSSION

The simulation model described is a useful analytic tool in that it provides the necessary means for evaluating the inherent protection in buildings and thus for developing a classification system for buildings relative to the prompt effects of nuclear weapons. Such a classification system currently does not exist. Once developed it would be used to provide on-site assistance at the local civil defense level; local officials responsible for emergency planning would have the means for classifying buildings under their jurisdiction in terms of direct effects protection levels.

Since it is also capable of performing damage assessment studies, this simulation model can and should be used by any Federal agency engaged in damage assessment. It is especially useful for those studies which are concerned not only with the effectiveness of a building as a whole, but with that of certain specific areas in a given building. The model has the capability of positioning personnel in any portion of a building and of predicting their relative safety.

The development of a concise building classification scheme requires data on the physical makeup of buildings. Since building types are numerous, an adequately large and representative sample is necessary. A current (all effects) survey being conducted by DCPA will provide detailed information on approximately 200 buildings representing the major structural types. This sample, if treated in its entirety, will provide an adequate base for the development of a classification system relative to prompt effects.

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DESIGN AND DEVELOPMENT OF A FOUR-FOOT BY SIX-FOOT EXPLOSION-PROOF WINDOW*

by
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and
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Good morning Gentlemen:

My topic is the "Design and Development of a Four-Foot by Six-Foot Explosion-Proof Window."

For the sake of organization of this presentation, I have sidestepped the chronology of the development and will present the material in the following order:

(1) An introduction as to the usage of the facility that demanded our explosion-proof window.

(2) The actual solution to our problem.

(3) The final proof test results utilizing the final configuration.

(4) Some of the development approaches and problems encountered.

In our area of concern, environmental testing, one of our missions is to evaluate the vulnerability of strategic systems to the effects of nuclear bursts in exoatmospheric space. One way to simulate part of the

*This work was supported by the United States Atomic Energy Commission.

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phenomena in question is to impulsively load the structure with explosives. One technique developed at Sandia Laboratories is to detonate sheets of primary explosives bonded to the exterior surfaces of the test item.

Ways of bonding a controlled sheet of explosives to the surface have been studied. From a control standpoint, a spray coating appeared desirable. Toward this end a spray technique and facility have been developed.

Our facility required a 4' X 6' observation window to allow an operator working with remote manipulation to mix the required explosive spray mix and to accomplish the actual spraying. It should be noted that the window is for operator protection during this phase in the event of an unintended detonation. Subsequent firing of the sprayed specimen is accomplished in an adjacent test facility.

The quantities of explosive to be sprayed set our explosive limit at the equivalent of 5 pounds of lead azide distributed as a thin sheet with a cosine distribution. This differs considerably from most high explosive fabrication and handling which is based on small, near spherical arrays.

To establish adequate factors of safety for this development, it was decided to do proof testing with 6 pounds of Detasheet C. The increased poundage and energy of this explosive would assure a factor of

safety > 2. The spray booth was to be constructed of frangible material other than the windowed wall to preclude any reinforcement of the shock front due to reflected pressures.

To make a lengthy story short, Figure 1 is an illustration of the window that has been developed. This slide illustrates the configuration of the window as set up for the final proof test. It consists of a welded steel frame inletted into a concrete barrier wall. This frame supports eleven 1-inch sheets of transparent plastic arranged as seen from the operator's side as follows:

(1) One polycarbonate (Lexan or Merlon)

(2) Three acrylic (Lucite or Plexiglas)

(3) One polycarbonate

(4) Six acrylic

The loads developed by the sheets are partially reacted by four 2-inch X 4-inch vertical steel beams welded into the frame and in contact with the sheet of plastic closest to the operating personnel. Retention of the plastic sheets is maintained by an over frame bolted to the spray-cell side of the main frame. Construction of the frame is of structural steel with the beams of Corten B. Total load on the window is carried as a shear load to the wall.

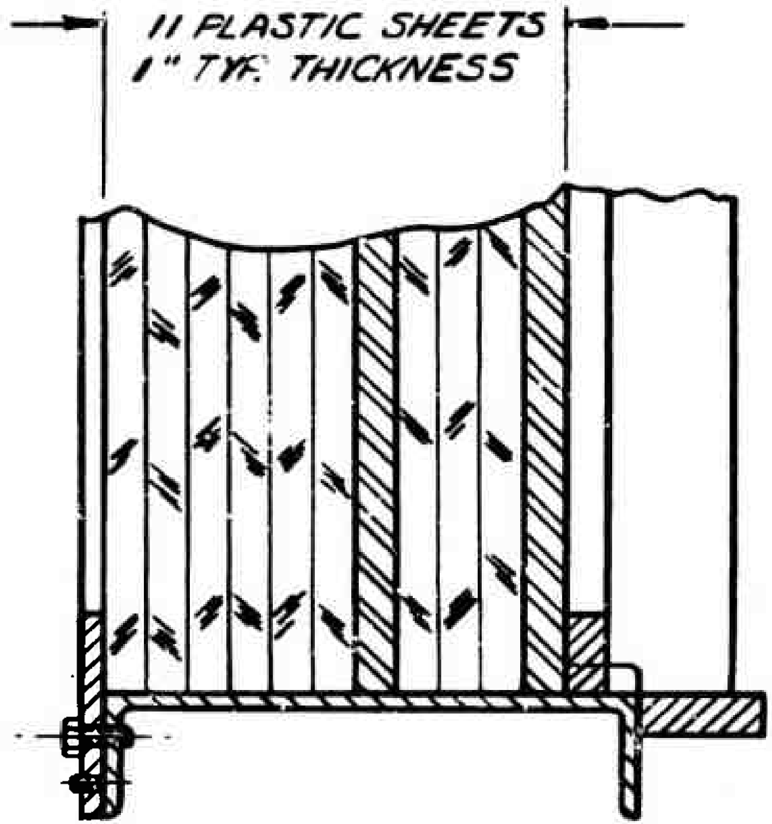


FIGURE 1.
CROSS SECTION OF PLASTIC SHEETS CLAMPED IN WINDOW FRAME

As can be seen in Figure 2, a phantom-lined triangular area is shown as the most likely position of the explosive with respect to the window.

Proof Tests:

The final test configuration is shown in Figure 3 and is a replica of the portion of the building which would experience the greatest stress. The test section is rotated from the vertical to the horizontal plane for economy reasons without sacrificing the accuracy of the test results. The top surface is a 12' X 12' section of the wall with the window embedded in it. The wall is supported on three sides, two of which are visible in the sketch. The two visible supports are the floor and roof of the building. The third support, which is not visible, is the outer wall of the building. The wall sections, the ceiling, and the floor are 12-inch-thick reinforced concrete. The two vertical members projecting from the wall are simulated manipulator tubes. The explosives were supported 5' above the window and were also in the horizontal plane. This structure was subjected to repeated proof testing with various plastic stacks. During the course of these tests, there appeared to be progressive plastic deformation of the backup beams.

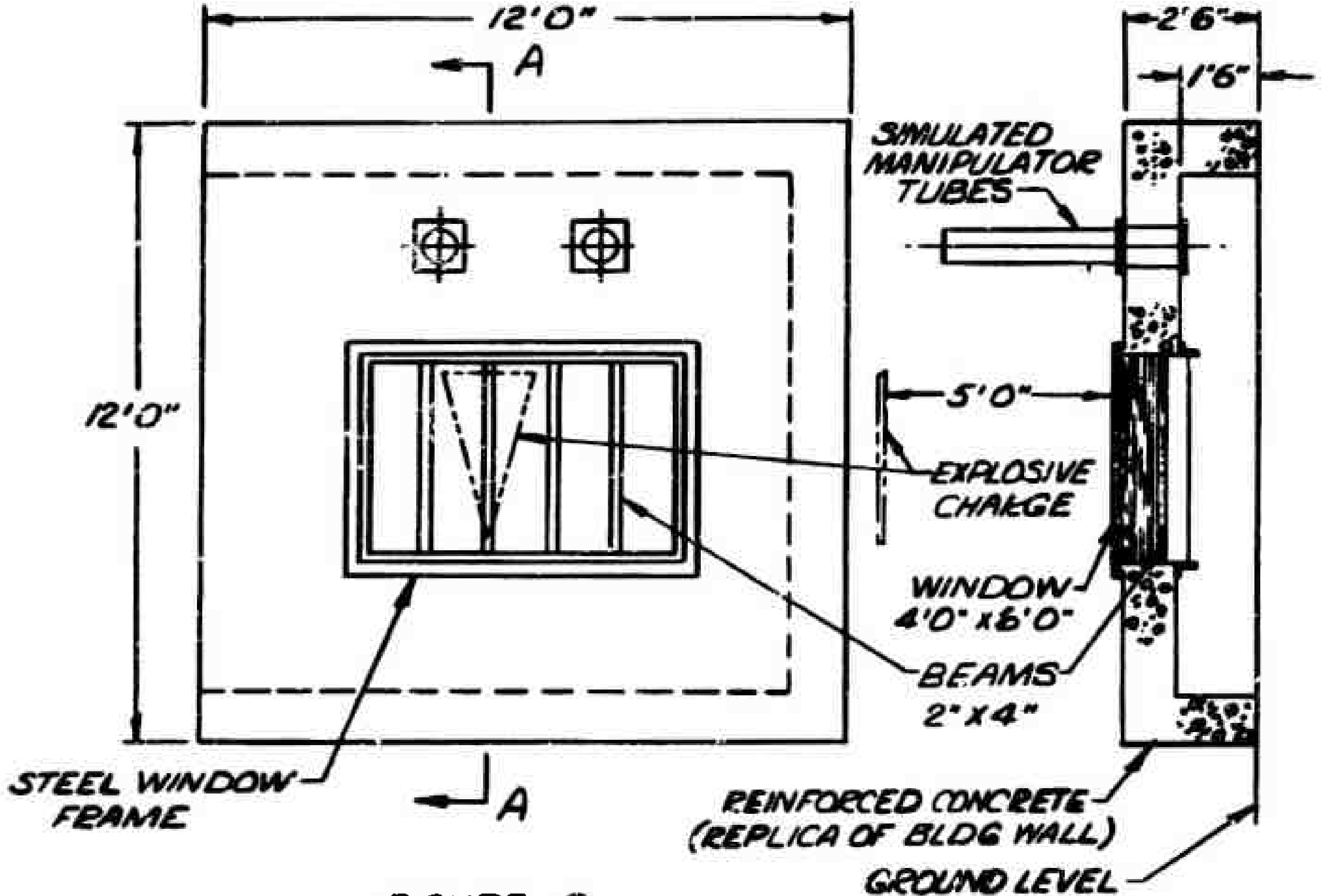


FIGURE 2.
LOCATION OF EXPLOSIVE CHARGE WITH RESPECT TO WINDOW & REPLICA OF THE BUILDING WALL

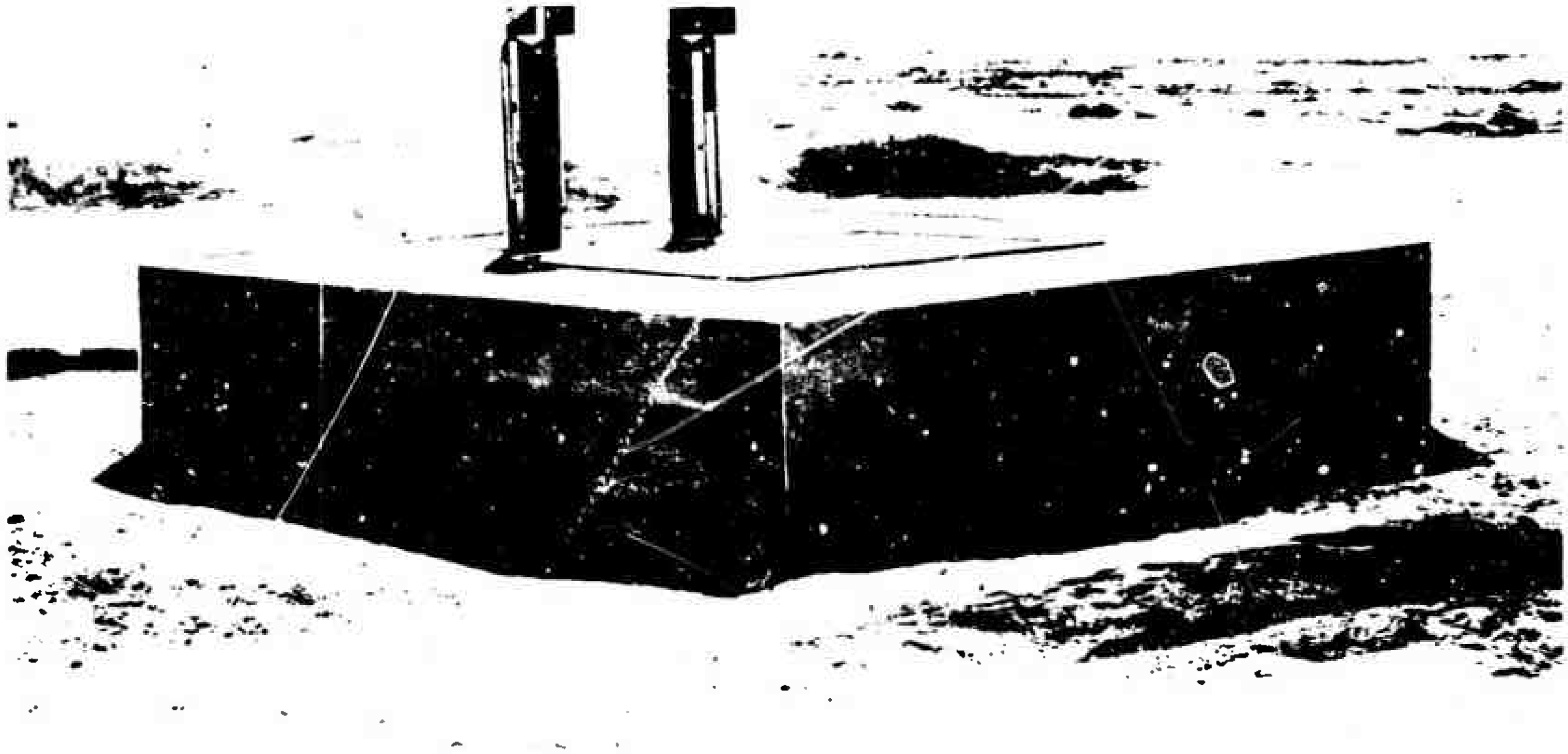


FIGURE 3.

WINDOW MOUNTED IN REPLICA OF BUILDING WALL

The final proof test was conducted with 6 pounds of Detasheet C ≈ 1/3 inch in thickness with shrapnel similar to that shown in Figure 4, and the plastic stack previously mentioned.

It should be noted that the explosives used were sheet explosives attached to plywood to give some degree of direction to the shock front.

Damage was as follows:

Pieces torn from the first sheet.

Next two sheets cracked.

Additional set to the 2-inch X 4-inch beams.

Development Aspects of the Window:

The development of this windowed facility initially was directed along the lines of existing explosion-proof windows with typical small windows and air-gapped transparent material.

Initial firing performance on small windows with an air gap configuration indicated to us that this was not the proper course of action when confronted with low pressure, high impulse loads. It was as they say, "time to fall back, regroup, and do a little engineering."

Theory was developed that indicated window mass was important since increased mass reduced the kinetic

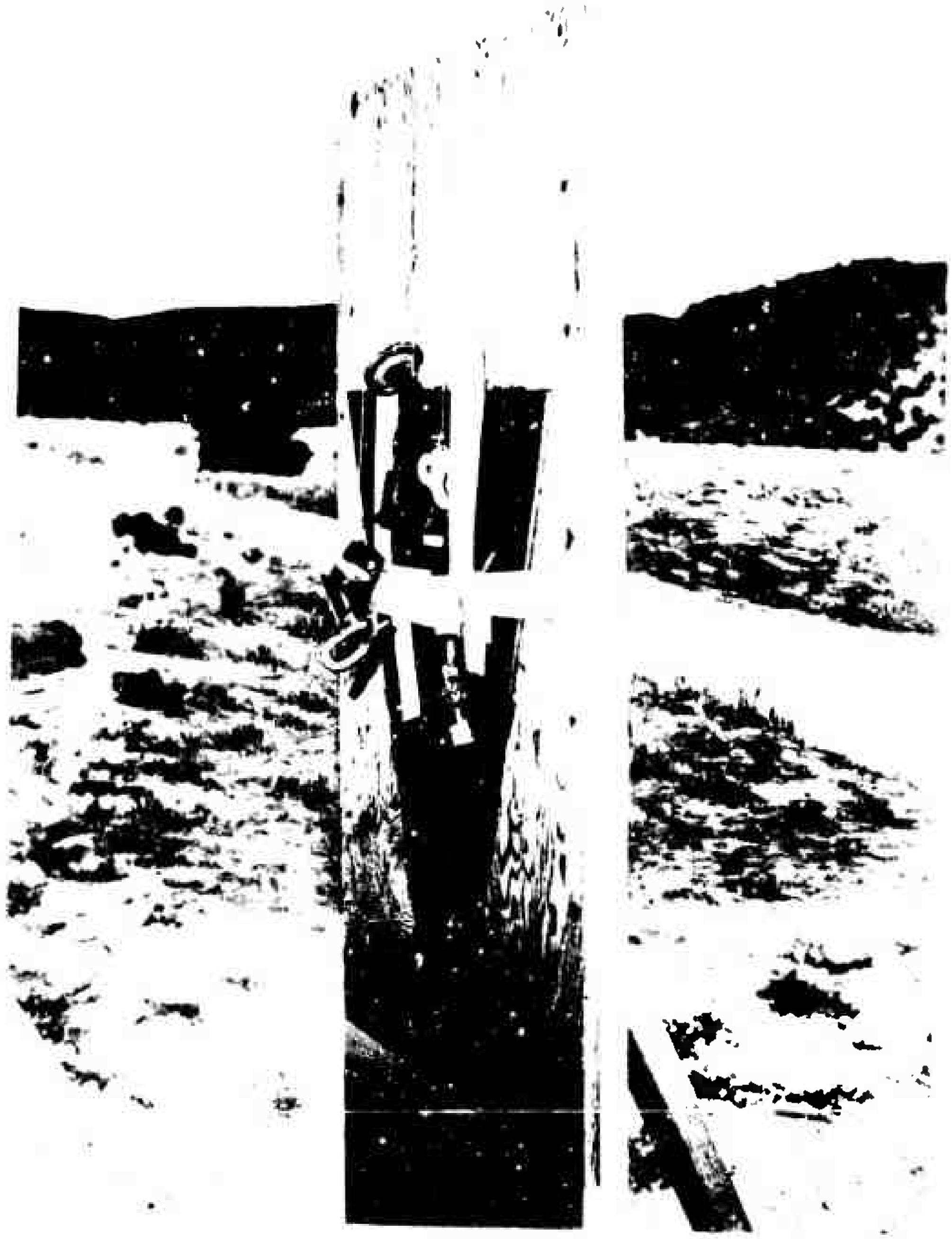


FIGURE 4.

MISSILES HELD AT SURFACE OF EXPLOSIVE

energy developed in the window due to the lower velocity resulting during the momentum exchange.

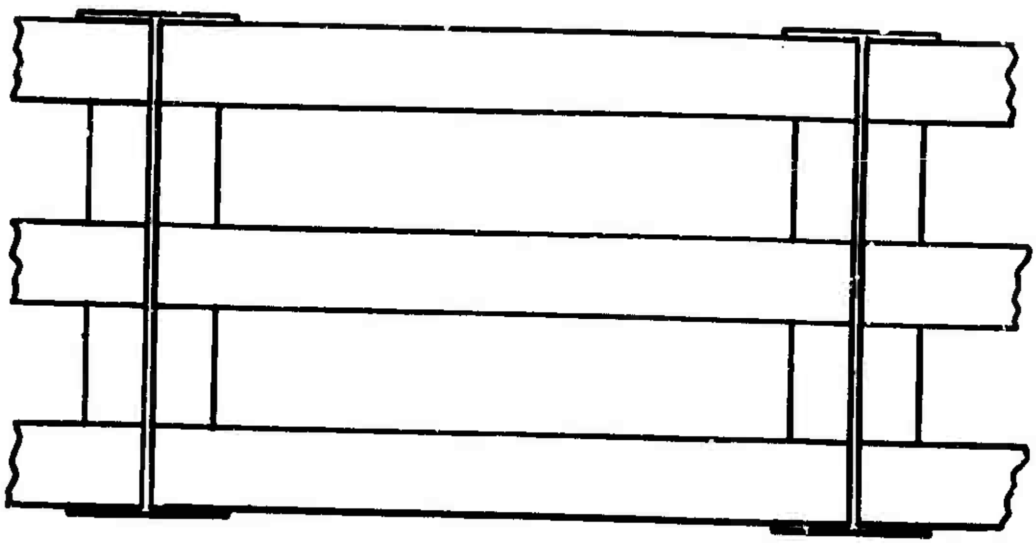
Figure 5 illustrates, schematically, the usual window design. This design is good for high pressure, low impulse loads where spallation is a problem. However, for our case an elastic beam on an elastic foundation proves to be most efficient. To help in the dissipation of energy, the backup beams are designed by plastic theory. This concept is also shown schematically in Figure 5.

This new concept was used in our design. The impulse data from the first firing was mathematically massaged to develop strain energy and subsequent material sizes.

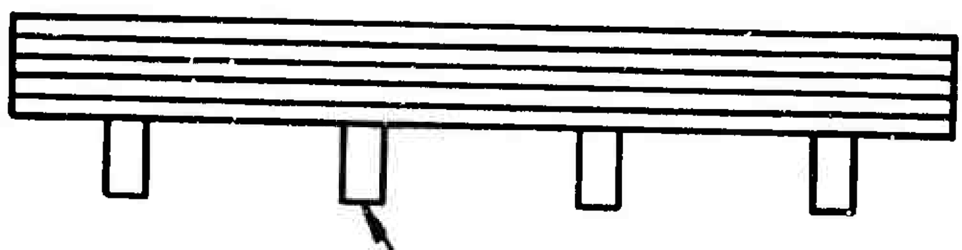
Data regarding window performance, i.e., the plastic sheets, was developed during the course of 13 firings. From this firing data, the performance of polycarbonate was superior to acrylic; however, the price and inferior optical properties of polycarbonate forced us to provide much of the mass with acrylic.

During the course of this study, other materials looked desirable (e.g., allyl diglycol carbonate and cellulose acetate butyrate), but their available sizes precluded their use and therefore their testing.

Attempts at stress analysis of the concrete wall-window combination will indicate the complexity of the problem with the configuration in question. Reasonable



USUAL WINDOW DESIGN



ELASTIC WINDOW DESIGN

FIGURE 5.
COMPARISON OF WINDOW DESIGNS

analytical agreements with test results were obtained by synthesizing a unit element strip across the wall and loading that strip. This technique, although useful, is somewhat wanting in regard to instilling confidence in the mind of the designer. It does, however, indicate a good starting point that can be proven-in by proof testing.

A Few Problems:

Other problem areas worthy of mention were encountered:

(1) Our strain-gage data on the beams indicated some strain hardening and subsequent shifts in loading. Any instrumentation used in developing a similar configuration should take this into account.

(2) There appears to be a tendency for the plastic retaining forward clamp plate to bow away from the plastic. This is attributed to rebound during the unloading phase.

(3) Quality welding is essential. Steps must be taken to assure competent welding. In our case, the welder had to be certified to the applicable portions of the ASTM Boiler and Pressure Vessel Code, Section IX, which was applicable to the welds at the junction of the four vertical

reinforcing beams to the outer steel frame. This certification required the welder to use specific materials, types of welding rod, welding position, etc., in making his qualification samples.

This is the story of our explosion-proof window. As can be seen, it is an admixture of empirical data taking and analytical fitting. Based on our findings, we believe that with a little theory development, a little initiative, and some good fabrication and testing, an adequate explosion-proof window system can be developed for most applications.

APPLICATION OF NEW SAFETY CRITERIA IN EXPLOSIVE MANUFACTURING FACILITY DESIGN

By

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ABSTRACT

This paper describes the conceptual layout of a modernized Load-Assemble-Pack (LAP) facility for processing 155MM, 175MM and 8-Inch Projectiles. Described are procedures used for the development of overall facility siting as well as design criteria utilized for the development of the schematics of individual buildings. Discussed in detail are the interrelationships which exist between the design of the process equipment, material conveyance system and the explosive safety aspects.

Presented also are a series of sketches illustrating building and site arrangements which will furnish the necessary safety and operational efficiency required of a new explosive manufacturing installation.

INTRODUCTION

Many high-explosive loading facilities now in use have been in existence since World War II or before. Some work has been performed in the past to improve the melt-load operation and other portions of load-assemble-pack (LAP) facilities. However, these improvements have been limited primarily to equipment modifications and some specific facilities (buildings, roads, services, etc.) changes. In order to meet the current production rate requirements, developments must be made in the field of automation which will also take into consideration the latest safety and pollution abatement regulations.

This portion of the paper describes one such facility where the latest state of the art for melting explosives, controlling automatic processes and temperatures, and handling and assembling materials, is employed. The material presented here is an updated version of the "Major Size Projectile LAP Line" (Reference 1) developed in connection with Steel City Task Force. This project was evolved by combined efforts of Picatinny Arsenal and U.S. Army Munitions Command (MUCOM).

The major size projectile line includes combined LAP facilities for 155MM (M107), 175MM (M437), and 8-inch (M106) projectiles (conventional projectiles as well as for the 155MM (XM650) and 8-inch (XM549)

rocket assisted projectiles (RAP). Facilities are available for loading Composition "B" explosive but these can readily be expanded to include the TNT loading facilities.

The work described in the paper was developed for the Manufacturing Technology Directorate of Picatinny Arsenal as part of their Modernization Assistance Program for MUCOM.

OVERALL FACILITY

The Major Projectile LAP Line is designed as a dual line facility; one-half of which will be built initially to process the three conventional projectiles, with the other half line to be built at a later date and being capable of processing either the conventional or the RAP projectiles. Production rates for both the initial line and the dual lines are given in Table 1. These rates have been based on current production requirements using 2-8-5 work basis and an effective work time of 400 minutes per shift.

For the purpose of discussion the overall facility (Figures 1 to 3) is divided into seven major areas depending on how and where the explosive operations are performed.

(1) Bulk Explosive Receiving and Processing Area

(2) Inert Material Receiving and Preparation Area

(3) Explosive Melting and Projectile Loading and Cooling Area

(4) Pre-assembly Area

(5) Assembly Area

(6) Cyclic Conditioning Area

(7) Packing and Shipping Area

(8) Washout Area

All structures of each area as well as the areas themselves are designed to provide a maximum operational efficiency and cost effectiveness between the three main components of the facility design, namely; (1) operating equipment, (2) conveyance system, and (3) safety requirements.

Positioning of the hazardous operations and separations between the facility structures have been achieved by satisfying the limitations imposed by the safety requirements (References 2, 3, and 4). The separations between the structures conform to at least intraline distances (I.D.). Because the nature of the project is to develop facility concepts for a hypothetical site of unlimited size, in cases where people are involved and where the operations permit, the separations between buildings have been increased to the inhabited building distances (I.B.D.). However, when these concepts are applied to an existing installation with limited space, the I.B.D. of the idealized facility would have to be replaced by I.D. These reduced separations require increases in strengths of blast receiving buildings to provide the same protection as afforded by the larger separations. It may be noted that the cost savings achieved with the use of shorter conveyors, ramps, roads, utilities, etc., associated

with a compact facility may be offset by the cost-increases to strengthen it.

BULK EXPLOSIVE RECEIVING AND PROCESSING AREA

The main structures of the Bulk Explosive Receiving and Processing Area are: (1) the Bulk Explosive Receiving Building, (2) the Bulk Explosive Unpacking Building, and (3) Automatic Inspection Buildings. Other auxiliary buildings include Explosive Collection Buildings and a Battery Charging Building.

The Bulk Explosive Receiving Building is designed to receive its explosive filler - Composition B - in 74 cubic foot tote bins (3650 pounds/bin) or in 55 pound cardboard boxes. Explosive allowance for the receiving dock is 225,000 pounds. However, the total explosive quantity in all three primary buildings may not exceed the maximum quantity at the receiving dock. Both the Inspection and the Unpacking Buildings (explosive processing buildings) are separated from the Receiving Buildings by unbarricaded intraline distances (U.B.I.O.) based upon the quantity of explosive in the processing buildings. However, as described later, both of these structures are barricaded (as per References 3 and 4) for the Receiving Building.

Receiving Building

The Receiving Building is designed to receive both railroad box cars and trucks containing explosives.

Provisions have been made for receiving new 80-foot box cars and 40-foot trailers. The exterior of the structure is constructed of "Strengthened Frangible Construction." This phrase implies that the materials of construction used to build the frangible portions of the blast resistant structures are strengthened such as to resist the blast environment associated with an incident overpressure of 1.2 psi.

The interior of the building (Figure 4) is divided into (1) on-line storage for both the box and the bin contained explosives, (2) mechanical area, (3) facilities for personnel working in this portion of the building, and (4) a tote bin decontamination bay. If empty tote bins are cleaned when returned to the explosive manufacturing facilities, then the last portion of the Receiving Building may be eliminated.

The on-line storage facilities for the box explosives consist of six row-four tier "feeder" racks, which by gravity, feed the belt conveyor transporting the boxes to the Unpacking Building. Provisions are also available to by-pass the racks, and thereby feed the conveyor directly from either the truck dock or the rail receiving platform. In order to maintain a safe spacing between the boxes on the conveyor, an automatic spacing station is provided at the beginning of the

conveyor near the racks. A clear separation of 12 feet between the two 55 pound boxes containing the explosive has been found to preclude propagation of explosion (References 5 and 6), but not fire. Therefore, the ramp leading to the Unpacking Building must be furnished with a deluge system or other means to prevent fire propagation between the buildings.

When the bulk explosive is shipped in tote bins, the full bins are transported to the Inspection Building with the use of fork-lift trucks to replace the empty bins.

Unpacking Building

Fifty-five pound cardboard boxes and the inner plastic liners are opened in the Unpacking Building. The boxes received by the conveyor for the Receiving Building are opened manually at a transfer station where the explosive is placed in a hopper and then into the tote bins. The bins are then conveyed to the Inspection Building using fork-lift trucks.

The portion of the Unpacking Building facing both the Receiving and the Inspection Buildings consists of a single reveted barricade supported by a reinforced concrete wall. The remainder of the structure consists of strengthened frangible construction.

A plan layout of the building is illustrated in Figure 5.

Inspection Building

The function of this station is to receive the bulk explosive in tote bins, and remove all magnetic and non-magnetic foreign materials from the explosive before being conveyed to the Melter Buildings. As mentioned earlier, the tote bins are transported from the receiving dock to the inspection station by the fork-lift trucks where the truck operator positions a bin into an automatic tilter. The tilter is equipped with interlocks to prevent accidental tilting of the mechanism until (1) the bin is properly positioned and locked in place, (2) a dumping funnel has been attached to the top of the bin, and (3) the operator has vacated the station with an empty bin. Completion of these operations in the Inspection Building will actuate a "Go" light on a control panel in the Receiving Building. Upon his return from the Inspection to the Receiving Building and noticing the "Go" light, the truck operator will trip the switch to tilt and discharge the bin in the Receiving Building. Contents of the bin will empty into a hopper which feeds the bulk explosive to a vibrating screen. Upon being emptied, the bin with the tilter will automatically return to an upright position and the interlock will disengage. The fork-lift truck operator is then permitted to return to replace

the empty tote bin in the Inspection Building and repeat the whole process. Other than the maintenance personnel who will enter the inspection cell randomly, the fork-lift truck operators are the only people permitted to enter the cell during the operation.

The Inspection Building (Figure 6) consists of two bays; the equipment in each bay is capable of inspecting 18,000 pounds of explosive per hour. The portion of the building containing the tote bins and tilters is located above the ground while the remainder of the building (including the above mentioned feed hopper) is positioned below the grade to minimize the height and cost of the protective barricade facing the Receiving and Unpacking Buildings. Although, the full depth of 30 feet below the ground is not required for housing the Composition "B" inspection equipment (which requires approximately 20 feet), the increased depth will provide sufficient room for expansion of the facility to include screening equipment for TNT in future. The barricade separating the tote bin portion of each bay from the other two buildings and the dividing wall between the two cells are laced reinforced concrete elements (Reference 7), whereas the other concrete walls of below the grade portion of the structure are not laced but are designed as retaining walls for the earth surcharge.

Acceptable material which has passed through the inspection equipment is conveyed to the Melter Building in 50 pound slugs through a pneumatic conveyor. The explosive is conveyed in slugs rather than in a continuous stream to minimize the possibility of transmitting a detonation in one building through the conveyor to the other building. To further minimize the propagation of explosion hazard, the pneumatic lines are equipped with detonation traps (Reference 8) a set (2 traps) of which is positioned every 30 feet along each pneumatic pipe line. The first 30 feet of the pneumatic line which leads from the Inspection Building is placed below the grade to shield the first two sets of traps along the line from the effects of an explosion in one of the adjoining structures.

Because the pneumatic conveyance system for explosives is still under development, its use in the design of a new facility may not be practical now. Therefore, the use of a more standard type conveyance system will be required. The U.S. Navy is presently in the process of performing bed-depth tests (Reference 9) to determine the permissible depth of explosives on belt type conveyors which will preclude propagation of explosion. Also the use of trolley conveyors using buckets spaced at safe distances is under investigation at Picatinny Arsenal.

Explosive Waste Collection System

Both the Unpacking and the Inspection Buildings require a vacuum system to collect the explosive waste. The system recommended consists of a wet-type primary collector in combination with a dry secondary collector and explosive waste collection facility.

The wet collector utilizes the water impingement technique and is placed within the operating bay it is servicing. The maximum explosive accumulation allowed within the primary collector is 5 pounds. Automatic equipment is provided to shut down a particular operation in the event that the 5 pound limit is exceeded.

Each wet collector is services by a dry secondary collector located within a vacuum collector building which is outside of the Operating Building. One vacuum building may contain more than one secondary collector depending upon the number of operating bays it services. However, any one collector building shall not service more than one operating building. Each secondary collector is furnished with its own vacuum producer.

To limit the quantity of collected explosive in a primary unit, each collector is serviced by a continuous flow of water which carries the explosive

in a one percent slurry form to an Explosive Waste Collection Facility (Bldg. 116-Figure 1). The slurry is then either pumped or trucked to an off-site Explosive Waste Disposal Facility. Exhaust lines for each primary collector unit must be individual pipes whereas a common header is used to connect all exhaust lines to the Collection Facility.

Figure 7 illustrates a schematic diagram of the explosive waste collection system.

Alternate Arrangement

An alternate arrangement for the Bulk Explosive Receiving and Processing Area which will decrease construction cost but will increase personnel exposure to explosive hazards, may be used in lieu of the arrangement previously described. Here, the Unpacking Building is eliminated and the opening of the boxes is accomplished within the Inspection Building where separate bays are provided specifically for this purpose. To prevent the box opening personnel from having to enter into the inspection bays, a "tiptrak" or similar type bucket-type conveyor is used to convey automatically the explosive between a box opening bay and its adjoining inspection bay. Conveyance of the boxes between the Receiving Building and the Inspection Building is accomplished using the belt conveyor as described

previously for transporting the boxes to the Unpacking Building. The ramp used for conveying the boxes may also be used for transporting the tote bins.

Figure 8 illustrates one possible arrangement of the Inspection Building which may be used with the alternate bulk explosive handling arrangement.

INERT MATERIAL RECEIVING AND PREPARATION AREA

This portion of the facility consists of one building containing the following operations; (1) inert material receiving and storage, (2) projectile preparation, (3) empty pallet storage and shipping, and (4) process control and personnel facilities (Figure 9). The building is constructed using the strengthened frangible construction and hence is separated from the other facility components by at least I.B.D.

The building contains an on-line storage (two-day supply) of inert projectiles, funnels, thread protectors, and funnel covers to replace those reusable items damaged during operation. The projectile storage consists of three high tiers of pallets conveyed to the projectile preparation area by fork-lift trucks.

The preparation of the projectiles consists of removing the projectiles from the pallets; placing them on carriers, creating vacuum in projectile interiors, paint touch-up; inserting of thread protectors, funnels and covers; and final checkout. These operations are performed in three similar areas (or lines); two of which service 155MM

projectiles and the third area services the 8-inch, 175MM and/or RAP projectiles. Except for paint touch-up and inspection, all projectile preparation operations are automated.

Projectile pallets are stored in a special area and then sent to the projectile manufacturing facility when needed. Transfer of the pallets to the storage from the projectile preparation areas is by means of conveyors.

The control area of the building contains the necessary equipment to monitor the facility operations between bulk explosive inspection and projectile cooling. This equipment includes both processing equipment controls, conveyor monitoring equipment and computer memory units. The personnel area includes offices, toilets, clothing changing room, lockers, and eating areas.

MAIN CONVEYANCE SYSTEM

Conveyance of projectiles from the Inert Material Building to other areas of the facility is provided by overhead chain driven "power-free" type conveyor. In the following discussion, individual projectiles are assumed to be mounted on individual carriers; however, the general principles of conveyance as described for individual carriers are also applicable to multriprojectile carriers.

Figure 10 illustrates the details of a projectile carrier. The carrier consists of a base platform supported by a support rod which in turn is suspended from an overhead carrier trolley. The platform is provided with special holders to receive the various size projectiles. The holders are an integral part of the platform to allow for ease of conversion from one projectile system to another. Each support rod is equipped with a top clamping/locking device which provides stability for the projectile. The clamp is adjustable and capable of receiving the various size projectiles.

As mentioned before, each carrier is powered by a chain driven overhead trolley. When arriving at an operating station the trolley may be disengaged

from the drive (Figure 11) thereby permitting the carrier to stop at the station. Engagement of the trolley will permit the carrier to travel to the next station. A carrier memory device (Figure 10) will automatically inform the operating station equipment whether an operation should or should not be performed. It should be noted that due to the presence of the carrier memory the computerized control system within the Inert Material Building will consist only of conveyor monitoring system rather than a performance system.

The projectile conveyance system will begin and end in the Inert Material Building. Carriers with empty projectiles (with thread protectors, funnels and funnel covers in place) will leave the building for processing (loading, cooling, assembly, etc.) in other buildings and, upon completion of which; will return for recycling. While in ramps, individual carriers will be 3 feet on centers (Figure 11) and the support rod of a carrier will act as a protective shield to prevent propagation of an explosion from one projectile to another. This 3 feet separation is based upon conveyor requirements to open and close switches between adjoining carriers. The conveyor

spacing exceeds the safe separation distances obtained from recent 155MM projectile propagation tests (References 6 and 10) where a 2-inch diameter steel rod, positioned between two projectiles spaced 2 feet on center, prevented propagation. These tests did not include projectiles with funnels and therefore an additional funnel shield is attached to each support rod. Verification of the effectiveness of this latter shield will have to be established. An alternate way of protecting funnels would be to use a heavy steel-cover placed over each funnel.

When passing through buildings, adjoining projectiles are positioned 18 inches on center. To achieve this clustering of projectiles, the carrier support rods are rotated 90 degrees relative to the path of projectile flow (Figure 11). Each carrier is provided with a swivel which permits this rotation. As previously mentioned, the carrier trolleys are disengaged at the work stations with an allowable accumulated spacing of 15 inches between carriers. Further description of the main conveyance system is given later in the Section titled"Transfer of Projectiles Through Buildings".

EXPLOSIVE MELTING, PROJECTILE LOADING AND COOLING AREA

This portion of the modernized facility is significantly different than similar portions of existing LAP lines. The melting, loading and cooling facilities have been separated from one another in order to achieve reduced concentrations of explosives as well as to separate the hazardous operations from the less dangerous operations. All three individual components are further subdivided and separated to limit the degree of damage in the event of an explosion in any one structure.

Each of the two operations, melting and loading, is carried out in two buildings; the explosive allowance of each building is 2,000 pounds. The cooling operation uses 16 buildings each of which has a maximum explosive limit of 15,000 pounds. One Melter Building and one Load Building are grouped together and they service one-half of the dual lines. Eight cooling buildings also serve one of the two lines.

Each group of the Melter and the Load Buildings is separated from the second group by I.B.D. to insure that the above-ground portion of each building of each group will survive the effects of a detonation in one of the buildings of the other group. On the other

hand, two buildings of the same group are separated by I.D. It is anticipated that in the event of an explosion in either the Melter or the Load Building the "receiver" structure of the group, in addition to the "donor" structure will be rendered inoperable. Because of the relatively low hazard involved in the projectile cooling operation, all Cooling Buildings are grouped together and due to the nature of their construction have been separated from one another by earth covered steel arch magazine separation distances (Reference 2).

Melter Building

Each Melter Building consists of three explosive bays positioned below the grade and mechanical equipment areas above the ground level (Figure 12). The two exterior bays are used for melting virgin filler (bulk explosive) whereas the center bay is used to melt the riser material waste from projectiles previously loaded. As will be explained later the riser melter bay, if desired, may be located in a separate building.

The risers are transported to the riser melter bay by means of a belt conveyor leading from another portion of the facility where the risers are

removed from the funnels. After being melted, the riser filler is pumped to the bulk explosive melter bays where it is mixed with the melted virgin filler.

As previously mentioned, the bulk explosive is conveyed to the Melter Building from the Inspection Building with the use of a pneumatic conveyor. After the melting operation is completed, the mixture of riser and virgin filler is continuously pumped to the Load Building through a thermally jacketed pipe. As in the case of the pneumatic conveyor, a series of detonation traps is also included in (a) the loading line, (b) the line used to pump the melted riser material to the virgin material melter bay, and (c) the line used for recycling of the molten explosive in the event that the Load Building can not accept the melted filler.

Because the explosive operations are conducted below the ground surface, the Melter Building may be considered as a barricaded building. To insure that propagation of explosion will not occur between the Melter and the Load Buildings or between the Melter and the Inspection buildings; the two sets of detonation traps are also positioned below the ground in a trench. It should be noted that in

Figure 1, the 115 feet of barricaded intraline distance (for 2000-pounds of H.E.) between the Melter and Load Buildings is measured from the edge of the detonation trap trench in front of the Melter Building to the edge of a similar trench at the Load Building. The maximum separation distance allowed between two adjacent sets of traps is 30 feet.

It may further be noted that the adjoining walls of Area 2 and Area 3 (Figure 12) are separated by an air space. This structure-design is based upon the assumption that Areas 1 and 2 will be built as a part of the initially constructed production line and that Area 3 will be added at a later date when the second line is constructed. Also, it is theorized that the wall of Area 2 will be designed to resist the soil surcharge (non-laced reinforced element) before Area 3 is built and therefore can not be considered as an effective dividing wall for separating Areas 2 and 3. The "new" laced wall which is a part of Area 3 will provide the protection required. In the event of an explosion in Area 2, the bay wall will fail and impact the new laced wall. On the other hand, if the explosion occurs in Area 3, then laced wall will deflect without impacting the

unlaced wall of Area 2.

Load Building

Explosive slurry is received at each Load Building (Figure 13) from its corresponding Melter Building, discharged into a hold tank, and then pumped (by vacuum) into automatic filler stations. Each Load Building is subdivided into two explosive bays each of which contains two stations. Each bay has an explosive allowance of 2,000 pounds.

Projectiles are received from the Inert Material Building at each station in groups of eight. Within the ramp between the two buildings (Inert Material and Load), the projectiles of each group are oriented similar to that described for projectiles passing through buildings. Alternate groups of projectile are fed to each Load Building. However, just before entering a building, each projectile group is preheated within the ramp to prepare it for loading.

Within each building the groups of projectiles are indexed into and out of the individual load station. Each station is so designed that the funnel covers are removed, the projectiles are filled and the funnel covers are replaced automatically.

After leaving the filler stations the

projectiles groups proceed out of the Load Building and into ramps leading to the Cooling Buildings. Once within the ramps, the groups of projectile are de-clustered and spaced at 3 feet on center with individual carrier support bars used as shields for the projectile (Figure 11).

Cooling Building

A total of 16 Cooling Buildings are required, 8 of which service each half of the dual line facility. Seven buildings are required to handle one-half of the total shift production with the eighth building used as a surge area. Each Cooling Building consists of a 34 ft. 6 in. wide by 216 ft.-0 in. long earth covered steel arch igloo (Figure 14). The explosive capacity of each structure is based upon the maximum explosive allowance, production rate, and a cooling rate of 4 hours for the 155MM projectiles.

Entrance to each igloo is from a common ramp leading from the Loading Buildings. The ramp is divided into two sections (Figure 15); each of which services one group of eight igloos. Because each half of the ramp will contain projectile at the same time, the rows of projectiles in each section is separated by a 1-inch thick steel plate protective

shield. The ramp is heated to prevent solidification of the explosive while being transported between the Load and Cooling Buildings.

Each projectile carrier enters an igloo through a concrete maze. Once inside the building, the conveyor system is subdivided into five sections which permits a larger accumulation of projectiles at any one time. The carriers with projectiles are lowered into a tank containing water; the temperature of which is maintained at 140 degrees. The conveyor tracks above the tank are sloped to permit an increase of the submerged depth of projectiles as they proceed from one end of the tank to the other. At the end of the igloo the carriers are raised up out of the tank and again are placed into a single row (3 feet on center) and allowed to pass out of the structure through another maze into the ramp leading to the next building. The exit ramp also has dual sections, similar to the entrance ramp.

PRE-ASSEMBLY AREA

The next area of the overall facility is referred to as the Pre-Assembly Area and consists of three buildings namely; (1) Pre-Assembly Building, (2) X-Ray Hold Building, and (3) Facing Building. The location of the various operations in different buildings was predetermined by the relatively high hazard of the facing operations in comparison to that of the other pre-assembly operations.

Pre-Assembly Building

The main operations performed in this building consist of; (1) funnel removal, (2) X-Raying of projectiles, and (3) X-Ray film processing. The building (Figure 16) is subdivided into two main areas; each of which has sub-areas for the above three operations. In the funnel removal and X-Ray areas, the building is subdivided by laced reinforced concrete and laced composite walls, respectively. The film processing for each line is separated by normal interior partitioning. Separation between the X-Ray and the other two areas is also accomplished with composite walls which are predetermined by the 10,000 pound explosive allowance of each X-Ray bay. Each of the other two explosive areas, which contain the funnel

and thread protector removal operations, has an explosive allowance of 1,000 pounds.

The interior of the building (funnel removal and film processing areas) is protected from a detonation in the ramps with the use of laced concrete walls positioned at each end of the building. Both the exterior and the interior blast resistant walls are provided with concrete mazes to prevent propagation of explosion from one area to another. The remainder of the building (roof, interior walls, etc.) is constructed of strengthened frangible construction.

As indicated in Figure 16, it has been assumed in the X-Ray bay that the projectiles will be transferred from the primary carrier to other conveyance systems within the X-Ray cells. In order to be assured that a projectile is returned to its original carrier after X-Ray, the carriers are detoured around the X-Ray cells. By insuring that each projectile remains on one carrier during the facility operation, will minimize the computer control flow of the projectiles. One way to minimize the length of the main conveyor as well as to eliminate the need for additional conveyance systems would be to permit the primary conveyance system to enter directly into

the X-Ray cells. Here, it must be assured that the casettes are rigidly attached to the projectile carriers to prevent any relative motion between a projectile and its associated casette. In addition to reducing the length of conveyors, this latter arrangement would also permit reduction of the building size.

X-Ray Hold Building

Like the Cooling Buildings, the X-Ray Hold Buildings (Figure 16) are also constructed of earth covered steel arch magazines. Two igloos are required; one for each line. Each igloo is 165 feet long and 25 feet wide. The projectiles enter through a maze at one end of the structure and exit through a similar maze at the far end.

Within the igloo the conveyor is subdivided into five lines to permit a one-half hour production capacity to be accumulated within the building until their release is indicated by the results of X-Ray film reading. An automated station within the igloo will receive instructions from the film process laboratory to inform the memory system of each carrier whether its projectiles can be rejected or accepted.

Except for maintenance personnel, no other people are required in this building.

Facing Building

Four Facing Buildings are required, two of which service each line. Each building is constructed of earth-covered metal arch magazine having interior floor dimensions of 80 feet-6 inches by 20 feet-0 inch.

Both the facing (or drilling) and three cleaning operations are performed in the Facing Buildings. Entrance to and exit from the building of the projectiles are similar to that of the X-Ray Hold Building. When leaving the Pre-Assembly Area, each projectile is furnished with a cover to prevent foreign materials from entering into the projectile cavity while it is moved to the Facing Building. These covers are removed upon entering the Facing Building and a second cavity sealer is inserted before the projectile leaves the building. If not installed in the Assembly Building, the projectile liner may be used as the second sealer.

All operations in the Facing Buildings should be automated and thereby eliminate the need for operating personnel.

ASSEMBLY AREA

Assembly Area consists of one building; the Assembly Building (Figure 19). This building contains oeprations such as: (a) projectile cleaning, (b) liner seating inspection, (c) insertion of supplementary charge, (d) preparation of warhead base threads, (e) installation of O-ring and assembly of motor body to war head, (f) fluoroscopic examination, and (g) repair of rejects. The last three operations are common only to RAP projectiles.

The building is divided into two main areas; one area to handle the conventional projectiles while the second to handle either the conventional or the RAP projectiles. Both areas are further subdivided into operating areas. The number of operations conducted in any one area is such as to limit the explosive quantity in the area to 1000 pounds or less of high explosive.

Division of main areas and their subdivisions is accomplished with the use of laced reinforced concrete walls. Laced walls separating adjoining subdivided areas are provided with mazes to permit movement of projectiles through the building.

CYCLIC CONDITIONING AREA

The Cyclic Conditioning Area consists of two similar buildings; one for each line. Each building (Figure 20) consists of a series of sixteen interconnected earth-mounded steel-arch magazines. Each magazine is 300 feet long and 13 feet wide.

The projectiles enter at a common transfer house for both lines. At this point the projectiles are transferred from the individual trolley conveyors to a pallet containing sixteen projectiles. Once the transfer is made, the pallet is conveyed to the first magazine by a belt conveyor at a speed such that only one pallet will be within the entrance tunnel at any given time. Upon reaching the first "conditioning tunnel," the pallets are placed on a roller conveyor and moved along the tunnel by gravity. After remaining a prescribed period of time within the tunnel, each pallet is transferred by high speed conveyor along a "connecting tunnel" to the second "conditioning tunnel." Only one pallet is transferred at a time with the pallets in each adjoining tunnel being shielded from the pallet being transferred. The connecting tunnel is graded upwards such that once within the second conditioning tunnel, pallets may again be moved by gravity. The use of the gravity system will significantly reduce power

requirements and will permit the use of inexpensive conveyors.

A forty-eight hour period is required for cyclic conditioning of both the 155MM and 8-inch projectiles; with individual temperature cycles being 12 and 6 hours for 155MM and 8-inch projectiles, respectivley. For the 155MM projectiles these cycling effects require that alternate groups of tunnels (4 tunnels per group) be used for each heating (140 degrees) and cooling (ambient) periods. For the 8-inch projectiles, alternate pairs of adjoining tunnels are used for each heating and cooling cycle.

After reaching the end of the last conditioning tunnel, the projectiles are transferred to a second trolley conveyor and forwarded to the next building. The empty pallets are returned by gravity to the transfer house at the beginning of the Cyclic Conditioning Area.

PACKOUT AND SHIPPING AREA

In this concept the packout and shipping facilities are positioned in separate buildings. However, if the overall land area of a facility is limited then these two operations can be housed in one building.

Packout Building

The Packout Building is divided into two primary areas; each of which services one production line. The operations performed in each area include (1) projectile weighing, stenciling; prick punching and installation of grommets, (2) ring gaging, inspection, and if required re-prick punching; and (3) zoning and palletizing. The first two sets of operations for each line are separated by a common laced concrete wall which divides the building into two primary areas. The third set of operations for both lines are positioned in one room. Areas containing individual sets of operations are separated from one another by laced walls which contain openings shielded by mazes to permit the flow of projectiles from one area to another.

The carriers used to convey the projectiles from the Cyclic Conditioning Buildings are also used to convey the projectile through the building to the

palletizing area. Here, the projectiles are removed from the trolley conveyor and zoned according to projectile weight. The zoned projectiles are then palletized in lots of 8 for 155MM projectiles and in lots of 6 for 175MM and 8-inch projectiles. To transfer the pallets to the Shipping Building, a belt type conveyor is used. Here, the pallets are separated based upon safe separation distances given in Reference 2.

Shipping Building

In general the Shipping Building consists of large shipping docks. Here, area is provided for on-line surge for accumulation of loaded pallets, three railroad car loading docks and a dock for loading truck vans. Explosive quantity allowance for each area is 50,000 pounds. Safe separation between areas is achieved with the use of Tee-barricades.

WASHOUT FACILITY

As previously stated, when the primary conveyor carrying the projectiles reaches the Cyclic Conditioning Building, all but the rejected projectiles are transferred to another conveyor. At this point, the empty carriers and those carriers with rejected projectiles are returned to the Washout Building. Because the projectile carriers from both production lines are returned on the same conveyor chain, the spacing between carriers are maintained at 1 foot - 6 inches on center.

Once at the Washout Building, the empty carriers are washed and the rejected projectiles are steamed out. In addition, the riser funnels, thread protectors, and funnel covers which are removed in the Pre-Assembly Building and conveyed to the Washout Building, are washed and placed on the clean carriers for return to the Inert Material Building. However, before washing, the risers must be extracted from the funnels. The risers are returned to riser-melter bays in the Melter building by belt conveyor. The conveyor ramp used for returning the clean carriers to the Inert Material Building is also used to house the riser conveyor.

The melted explosive from the rejected projectiles and the residues from the funnels, thread

thread protectors and carrier wash waters must be processed into a flake or pellet state. Basic equipment used for melting and flaking riser material may also be used for processing above explosive material waste. In the event that the risers are also processed with the other explosive material waste in the Washout Building, then there is no need for positioning the riser melter bays in the Melter Building. Here, the flaked riser material would be returned to the Inspection Building for mixing with the virgin filler material.

Figure 23 illustrates a possible layout of combined Washnut and Riser Melter Building.

TRANSFER OF PROJECTILES THROUGH BUILDINGS

Figures 24, 25, and 26 illustrate a possible method of transferring projectiles through the operating building. Here, a time history of the projectiles' movements in entering, passing through and exiting the building is presented.

At time zero (Figure 24), the first carrier arrives at the accumulation station immediately exterior of the building. After thirty seconds, the first set of eight carriers are accumulated at 15-inch spacing. (Carriers are spaced 3 feet on centres when passing through the ramps.) After the next fifteen seconds (time-45 sec.) the set of projectiles enter the maze but they are still considered exterior of the building because they are still subjected to propagation due to an explosion at the side of the building. Fifteen seconds later, the first set of projectiles move partly through the maze. Since these projectiles are shielded from other projectiles outside of the building, they are considered to be located within the building. As the first set is entering the building, a second set of projectiles has fully accumulated at the station outside the building (time-60 sec.). In the next forty-five seconds, the initial set of projectiles enters into the first operating station, the operations are performed

on it, and then leaves the station vacant for the second set of projectiles. During the following sixty seconds, the initial set of projectiles will pass through the second maze and thereby leave the building. Once out of the structure, the set of projectiles are declustered and continue along the ramp at 3-foot separation.

In the above description, it is assumed that the time for performing individual operations will not exceed fifteen seconds. In the event the operating time exceeds 15 seconds, then the number of parallel stations must be increased to that corresponding to the number of 15-second intervals in the total operating time. The above operating time of 15-seconds is based on a conveyor speed of 60 feet per second within the building. A higher speed will permit an increase in the operating time.

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3. Dobbs, N., et al., "Approved Safety Concepts for Use in Modernization of USAMUCOM Installations-Safety Engineering in Support of Ammunition Plants", Technical Report No. 4420, Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey, October 1972.

4. Forsten, I., and Parker, R., "Safety Design Technology for Plant Modernization: Approved Safety Concepts for use in Modernization of USAMUCOM Installations", a paper presented at the 14th Annual Explosive Safety Seminar, New Orleans, La., November 8-10,1972.

5. Rindner, R., and Anderson, C., "Propagation Tests of 55-Pound Boxes of Bulk Explosives", Preliminary Draft, Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey.

6. Rindner, R., "Safety Design Technology for Plant Modernization: Explosive and Ammunition Sensitivity Tests", A paper presented at the 14th Annual Explosive Safety Seminar, New Orleans, La., November 8-10, 1972.

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10. Anderson, C., and Rindner, R., "Separation Distance Tests of 155MM (M107) Projectiles", Report No. 4425, Safety Engineering in Support of Ammunition Plants, Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey, November 197?.

TABLE 1 - PRODUCTION REQUIREMENTS

PROJECTILE / PRODUCTION RATE (1)	CONVENTIONAL			RAP	
	8-Inch (M106)	175-MM (M437)	155-MM (M107)	8-Inch	155-MM (XM650)
PER MONTH	200,000	287,280	520,800		
PER SHIFT	4,763	6,840	12,400		
PER MINUTE	12	17	31		

(1) Work basis /2-8-5 (400 minutes effective shift)

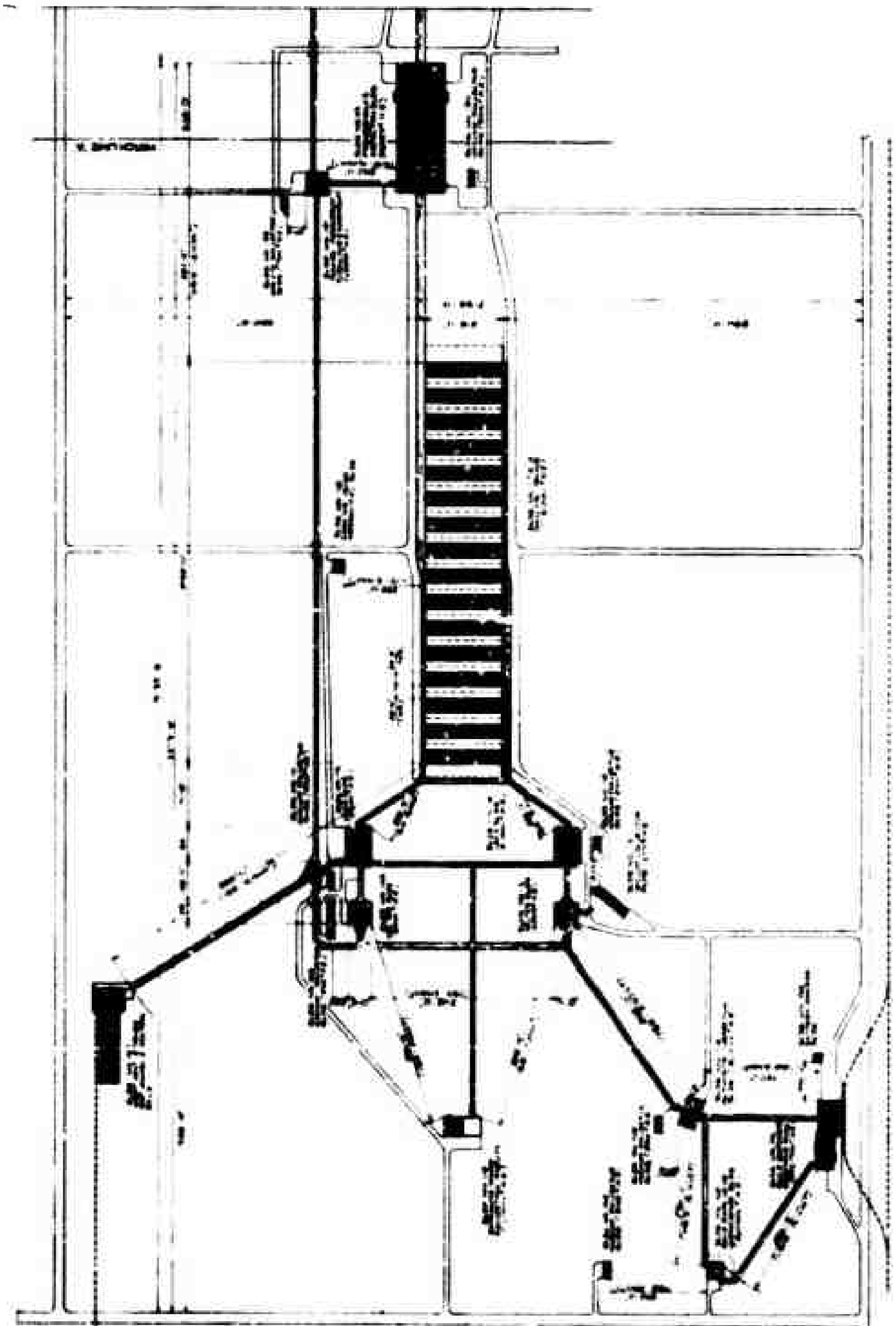

FIG. 1 FACILITY SITE PLAN (SECTION – I)

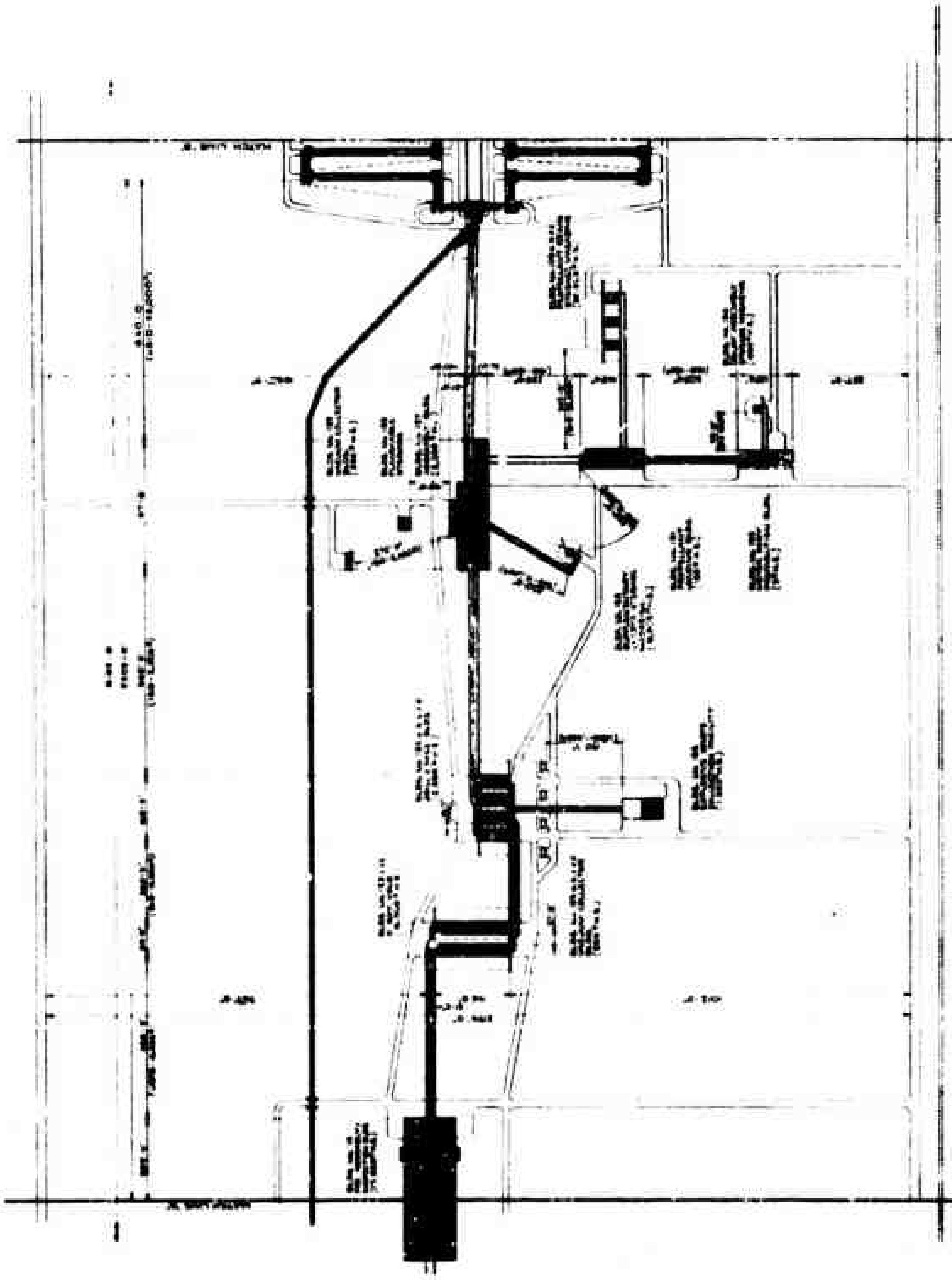

FIG. 2 FACILITY SITE PLAN (SECTIC.J - 2)

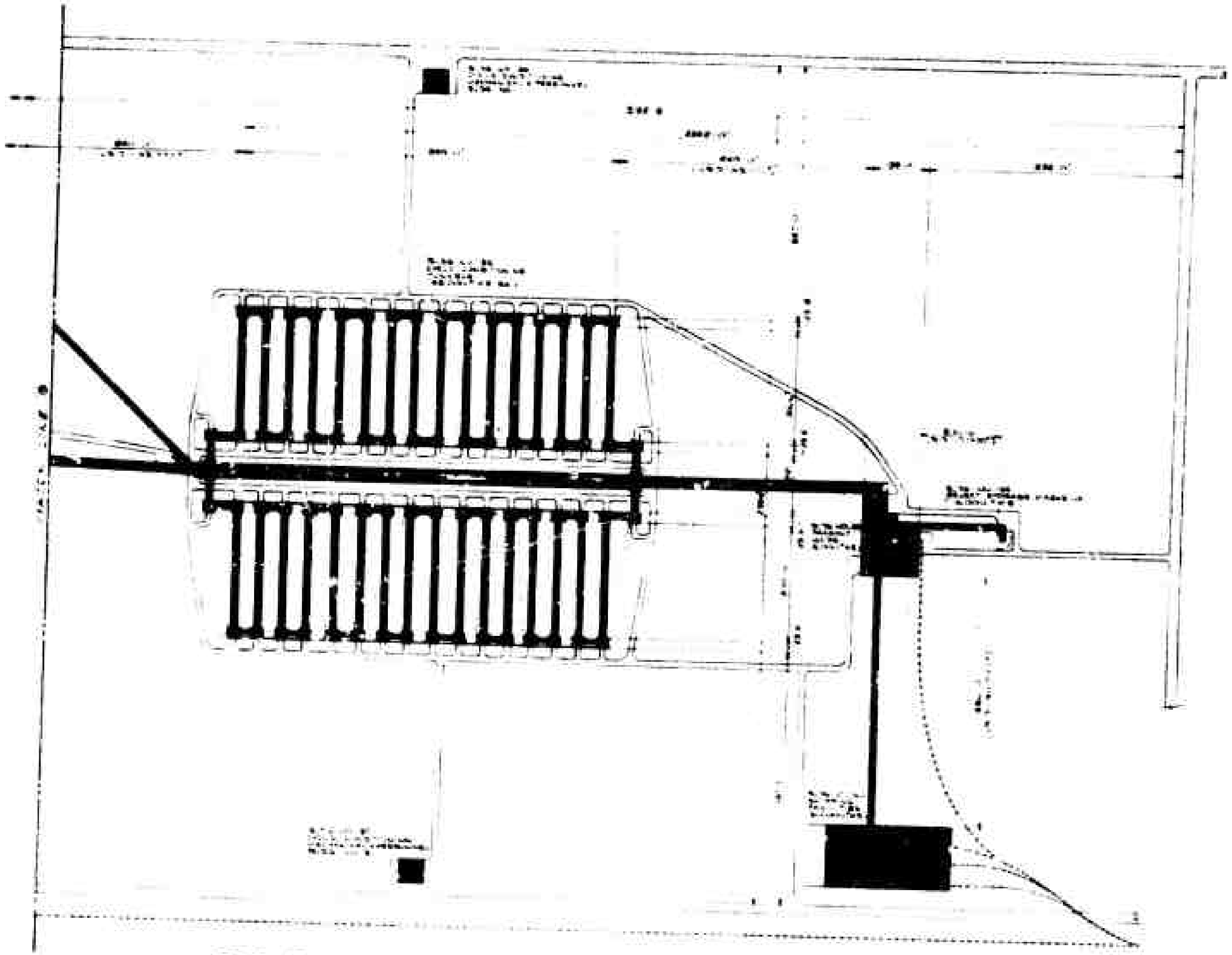

FIG. 3 FACILITY SITE PLAN (SECTION - 3)

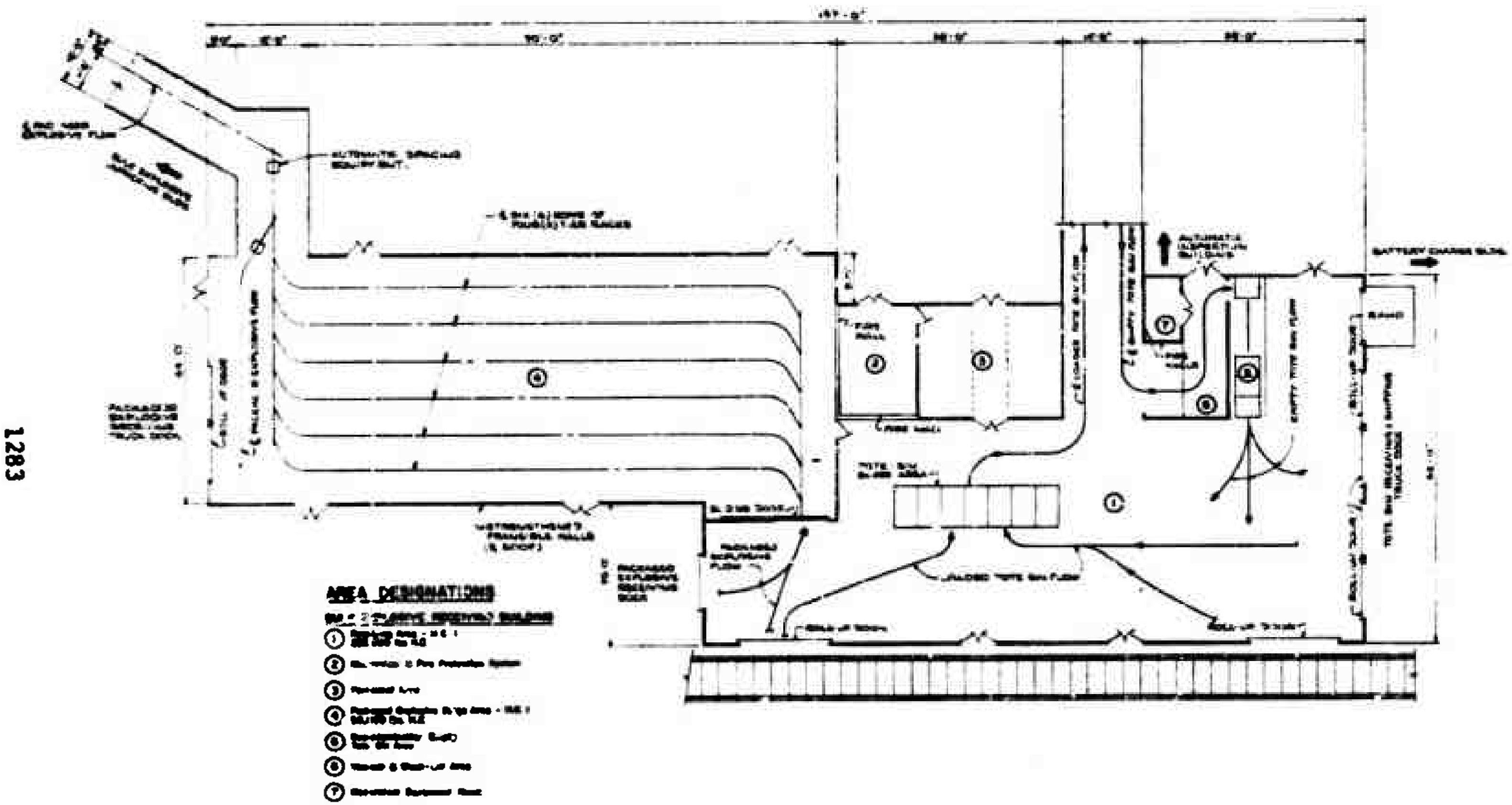

FIG. 4 BULK EXPLOSIVE RECEIVING BUILDING, BLDG. NO. 101

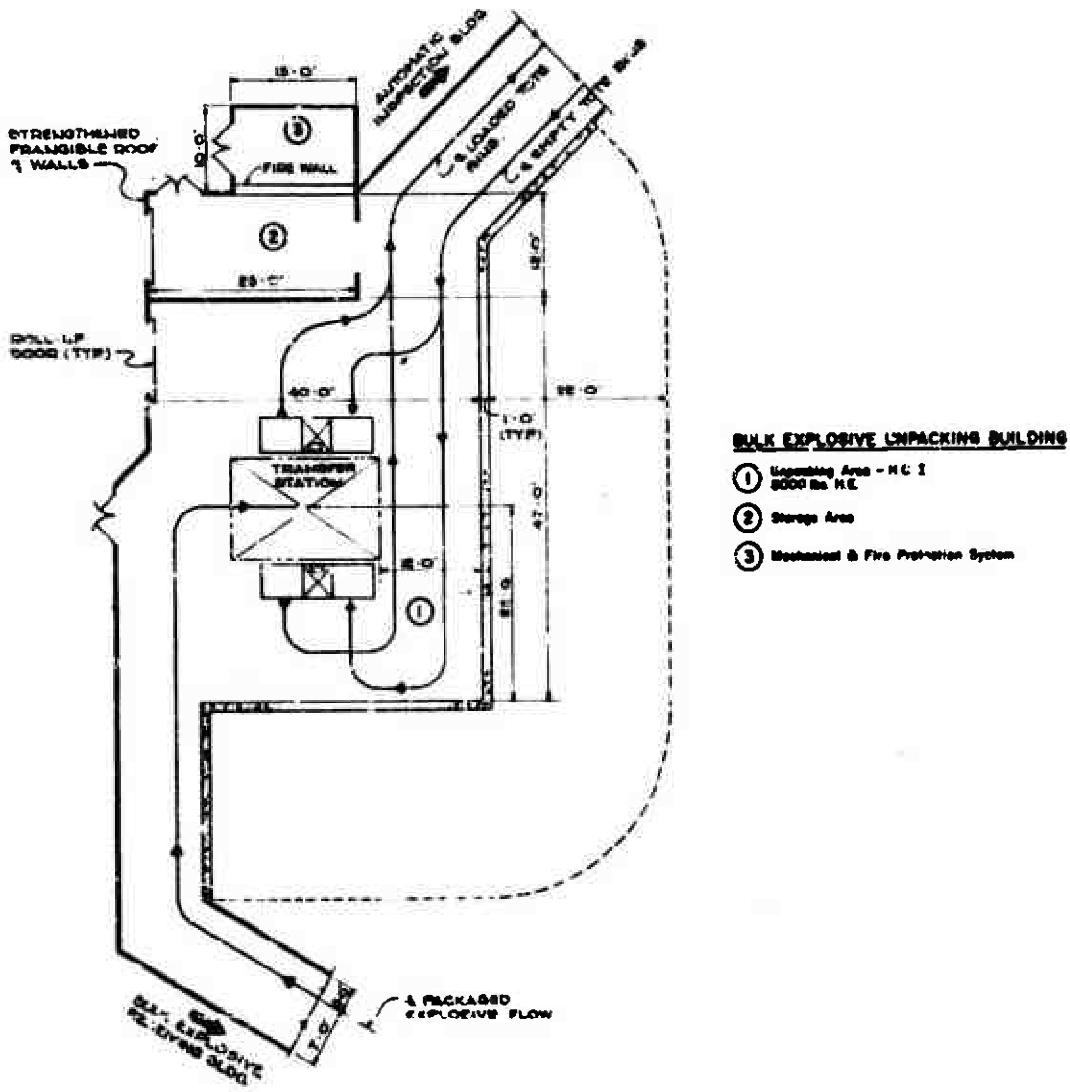

FIG. 5 BULK EXPLOSIVE UNPACKING BUILDING, BLDG. NO. 112

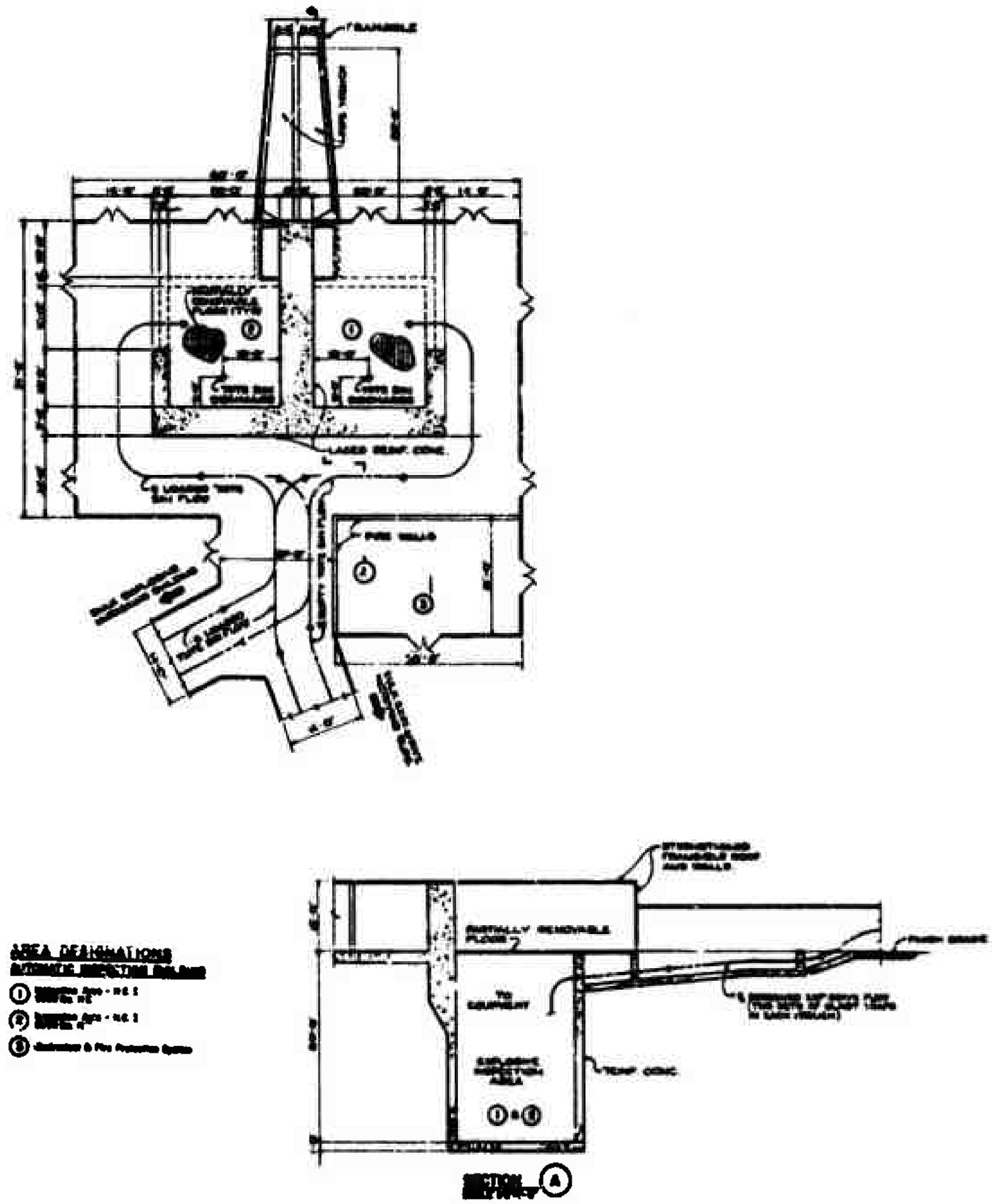

FIG. 6 AUTOMATIC INSPECTION BUILDING, BLDG. NO. 104

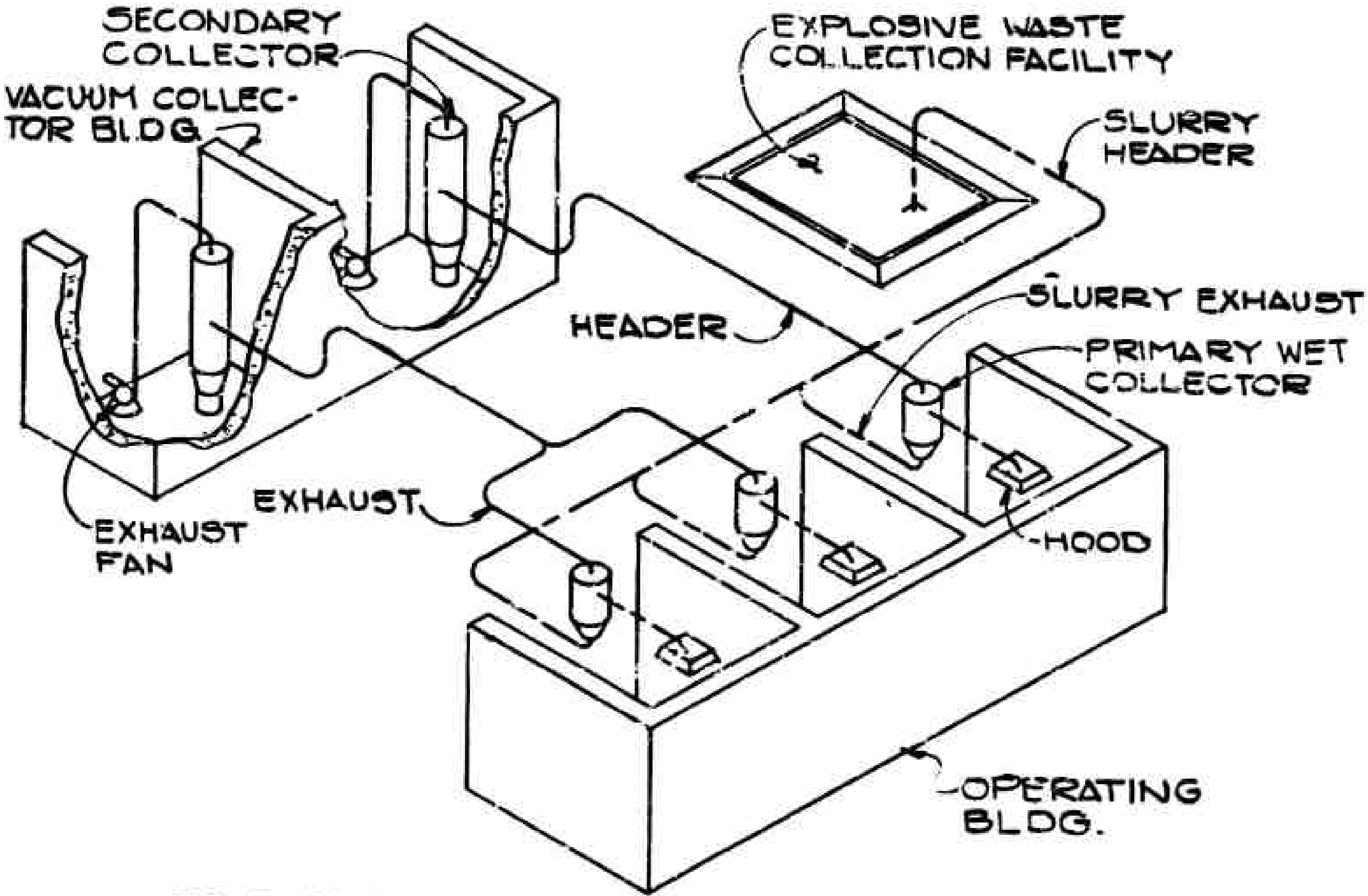

FIG. 7 SCHEMATIC OF EXPLOSIVE WASTE COLLECTION SYSTEM

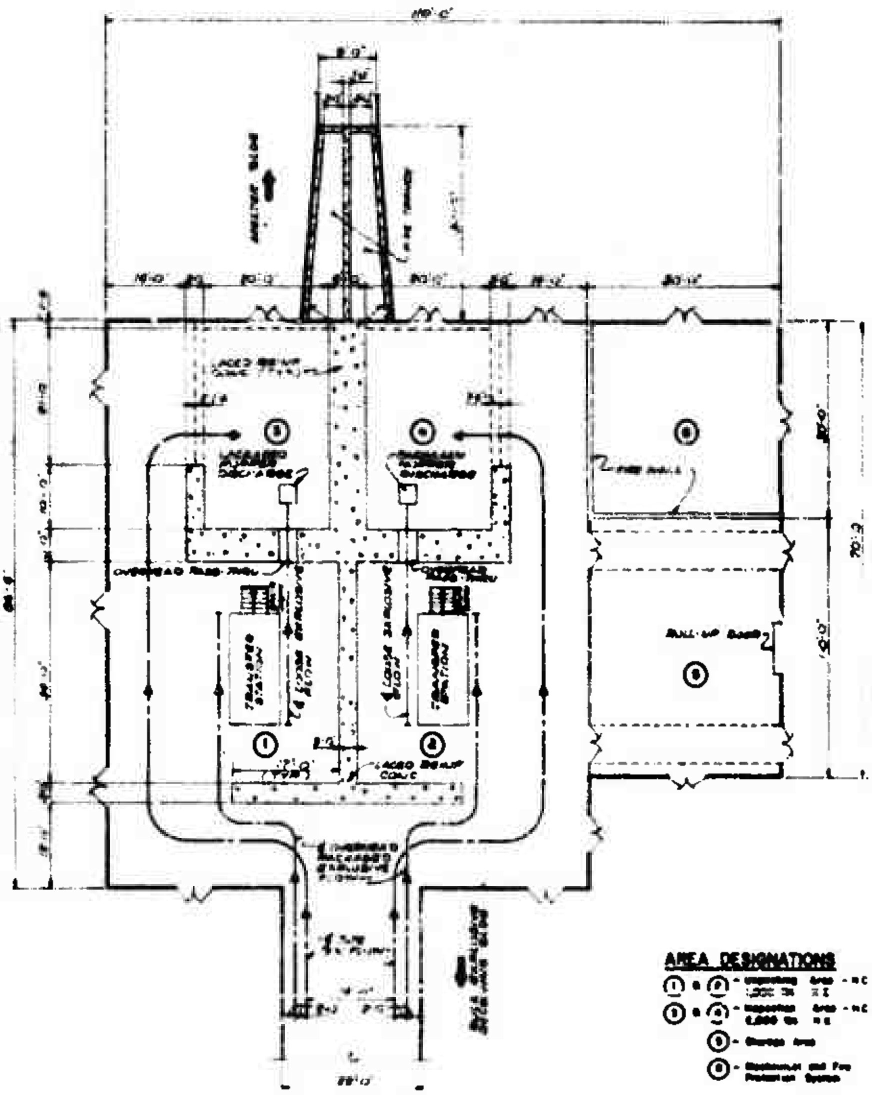

FIG. 8 COMBINED UNPACKING AND INSPECTION BUILDING

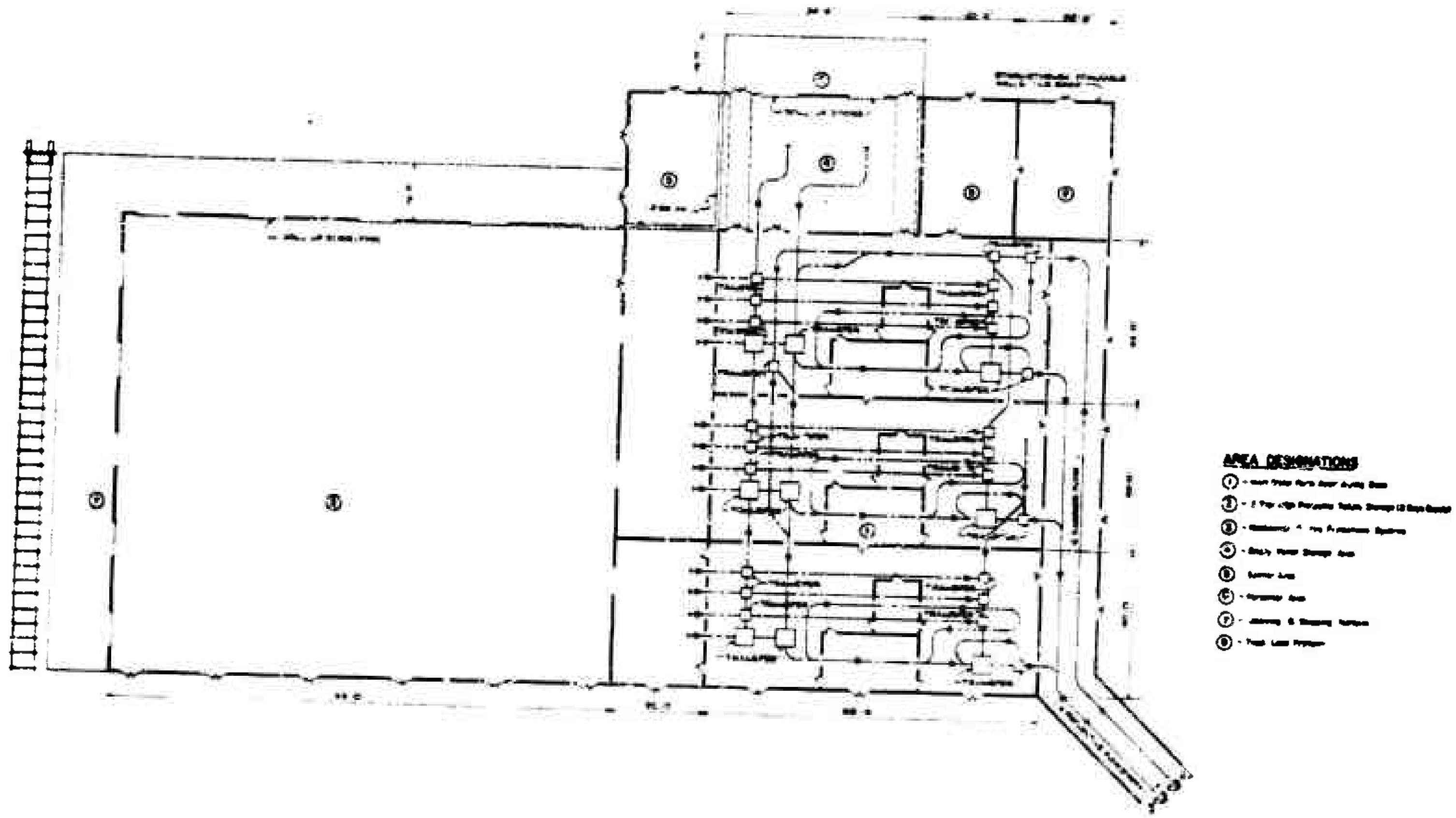

FIG. 9 INERT MATERIAL STORAGE, PERSONNEL & CONTROL AREA, BLDG. NO. 107

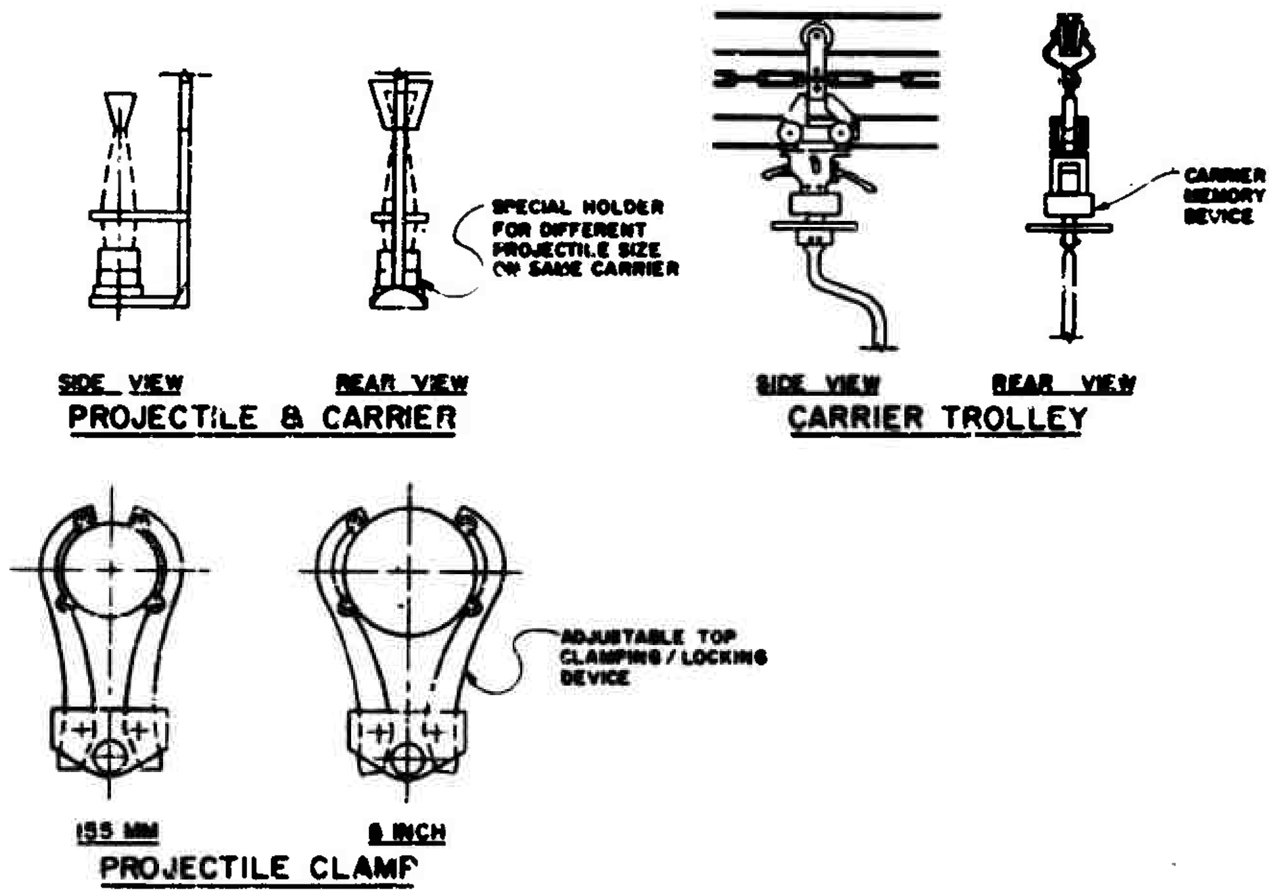

FIG. 10 CARRIER DETAILS

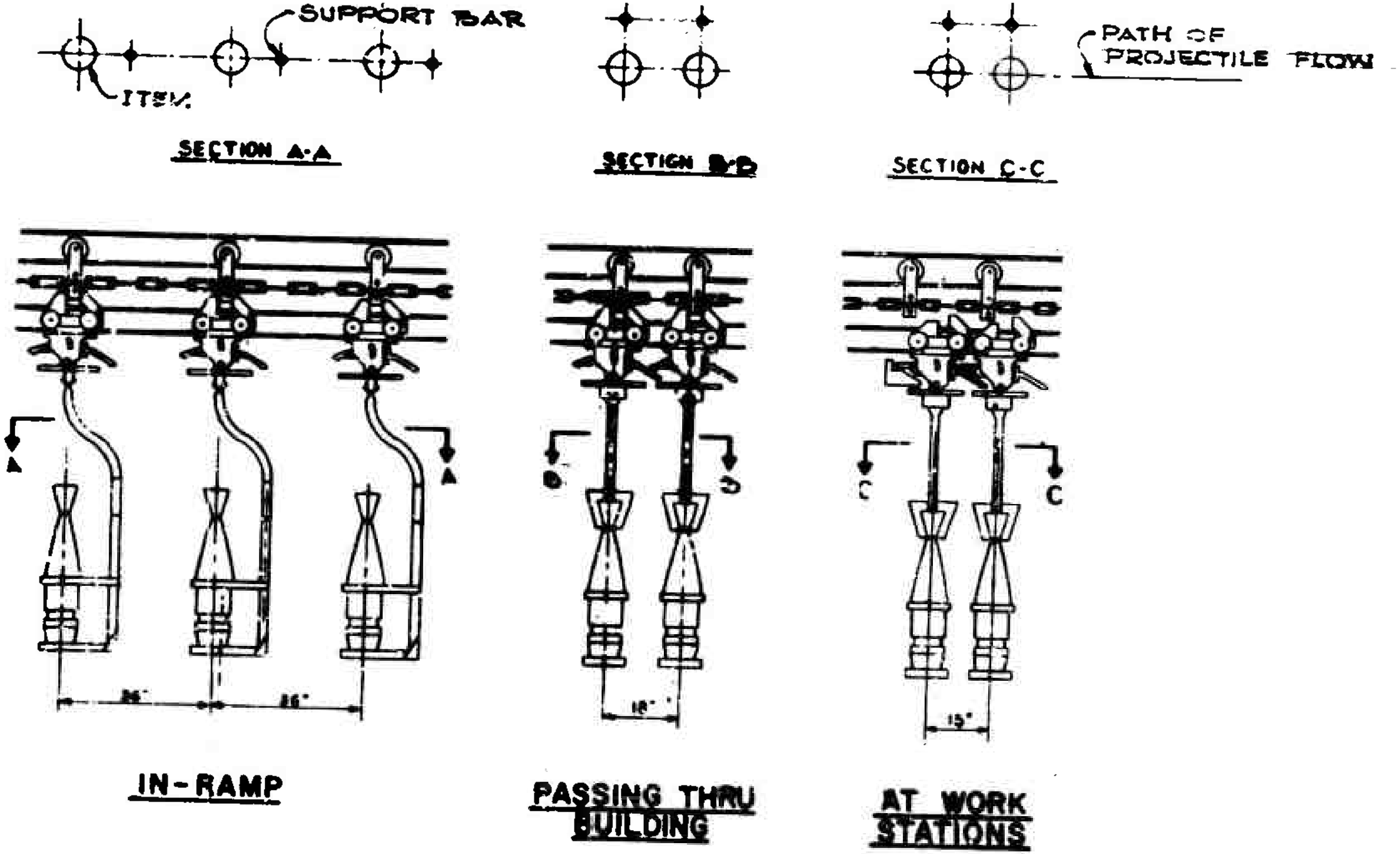

FIG. II ITEM CARRIER ARRANGEMENT

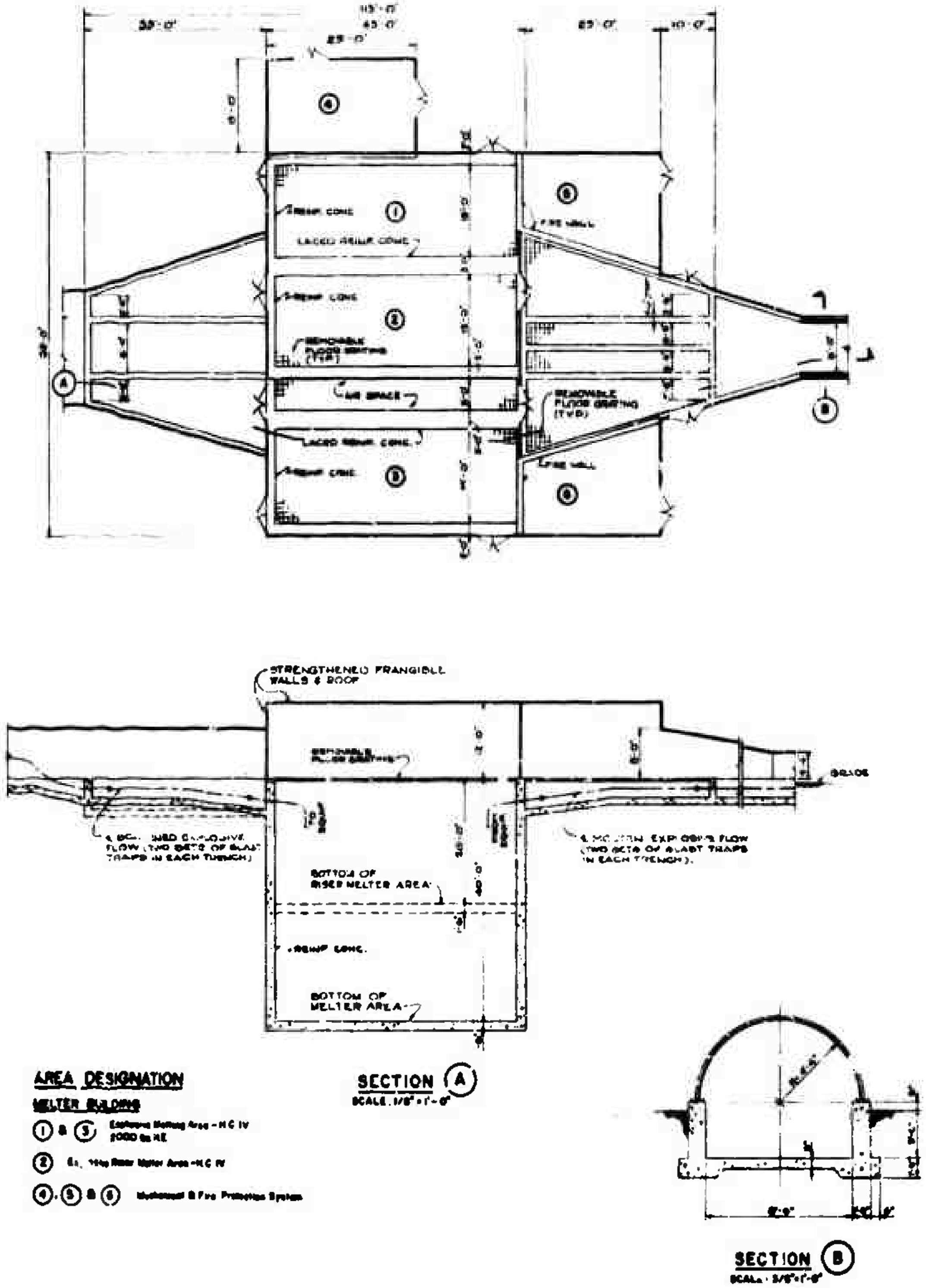

FIG. 12 MELTER BUILDING, BLDG'S NC'S 108 & 112

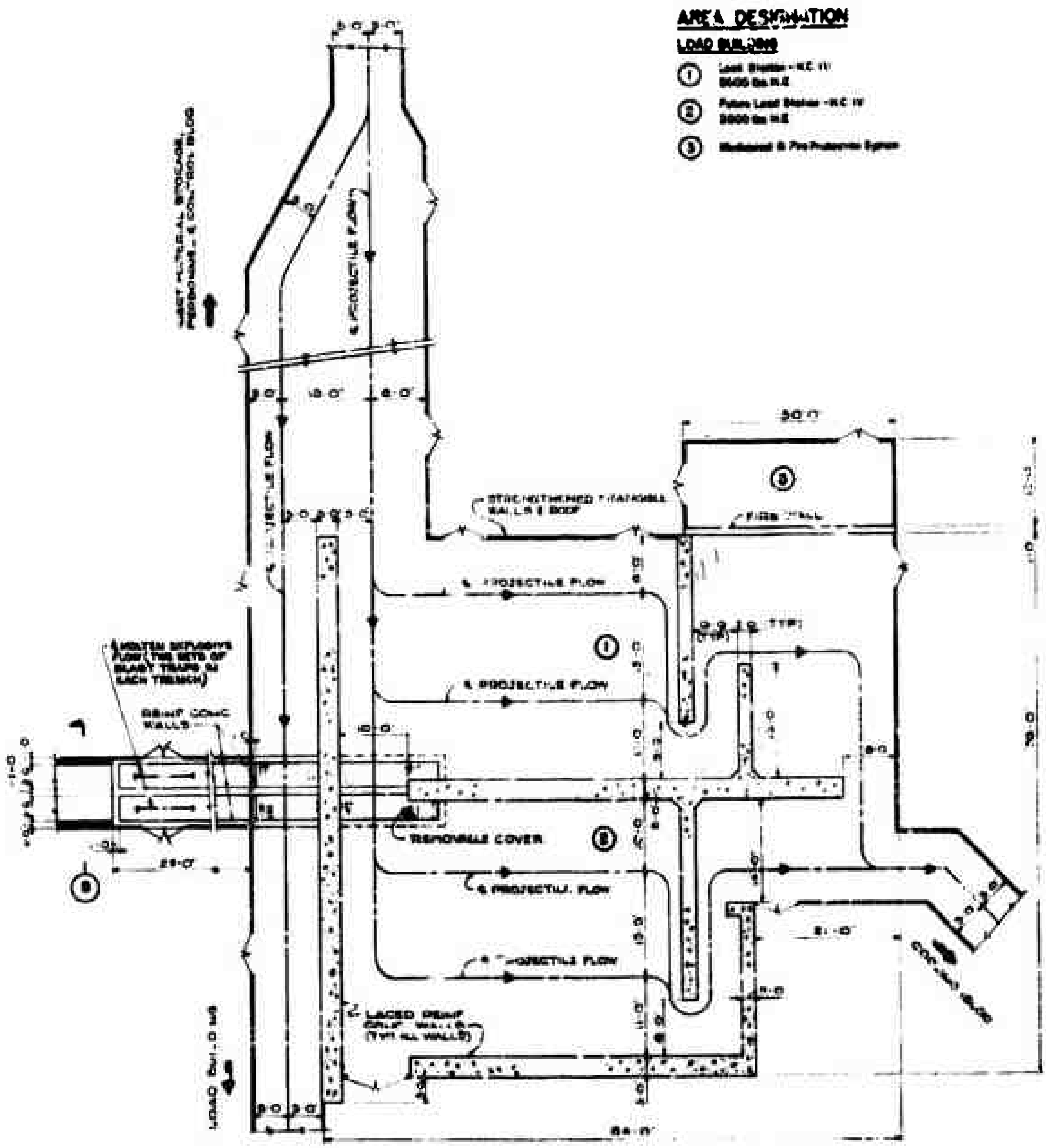

FIG. 13 LOAD BUILDING, BLDG'S NO'S. 110 & 114

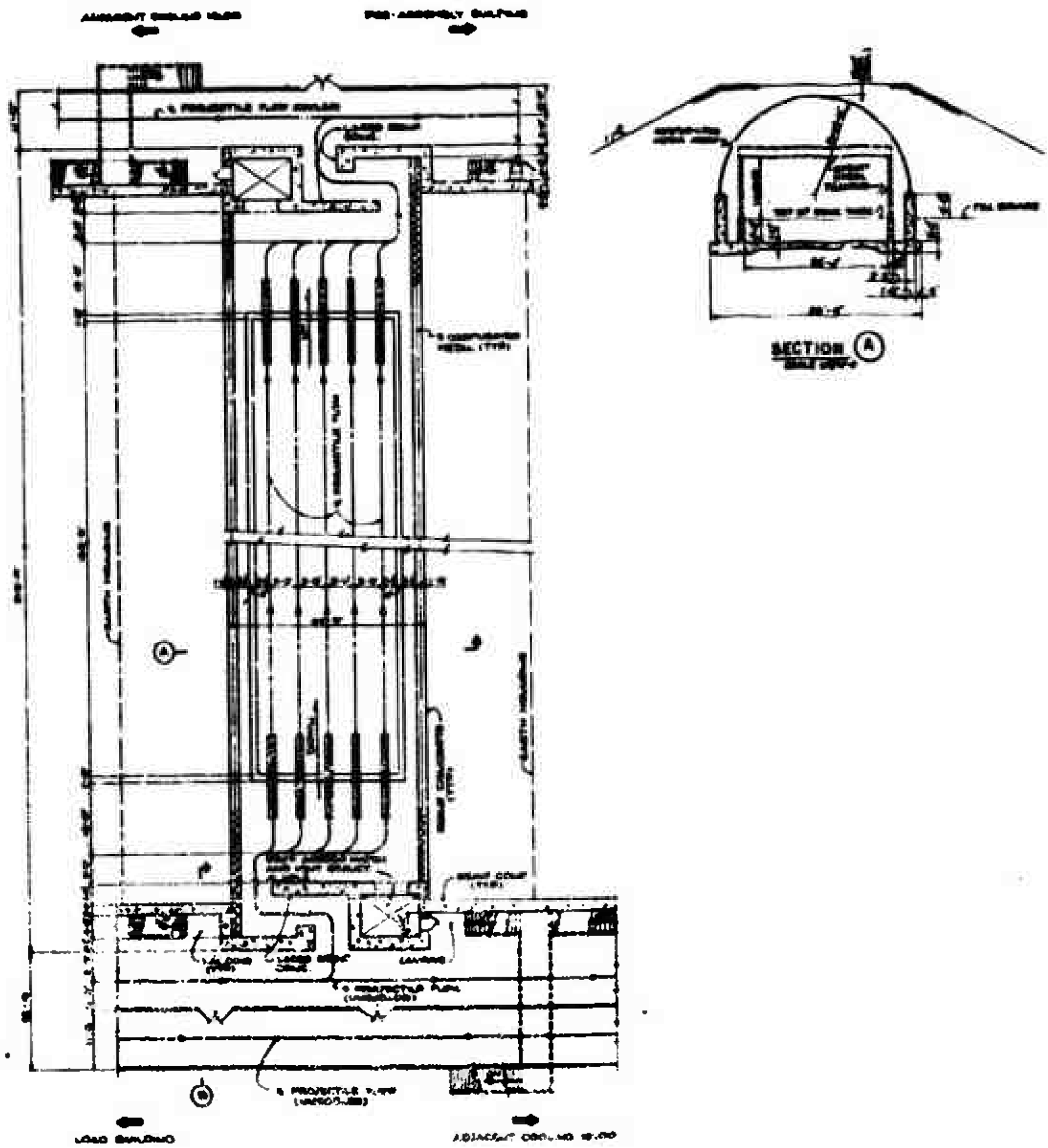

FIG. 14 COOLING IGLOO, BLDG. NO. 117

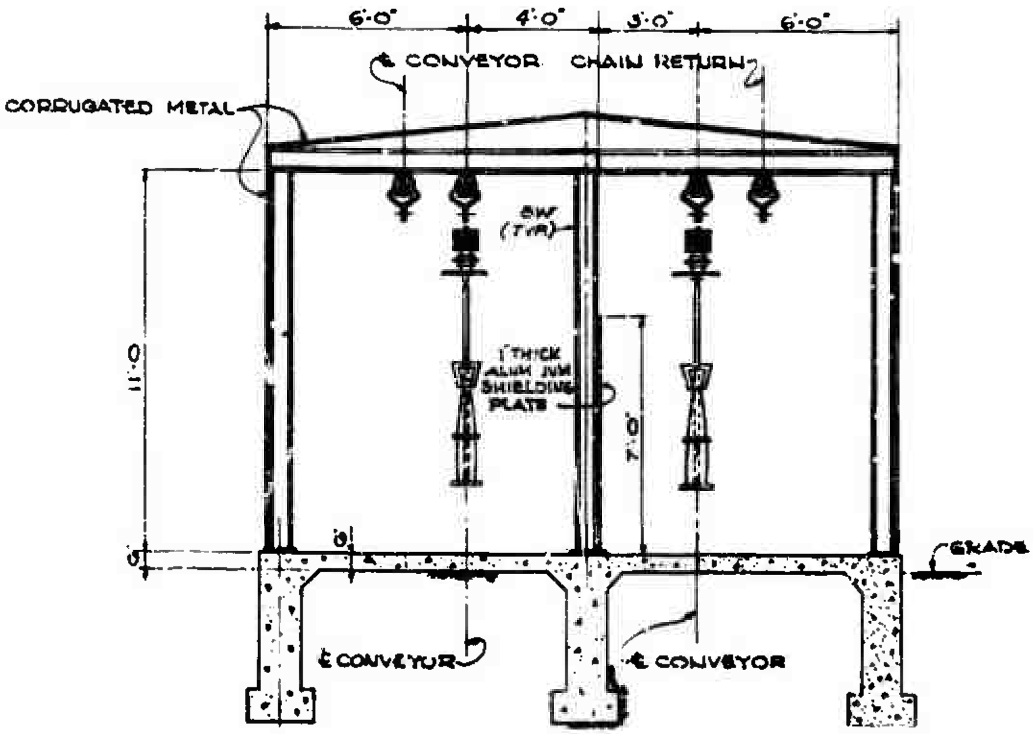

FIG. 15 TYPICAL DOUBLE RAMP

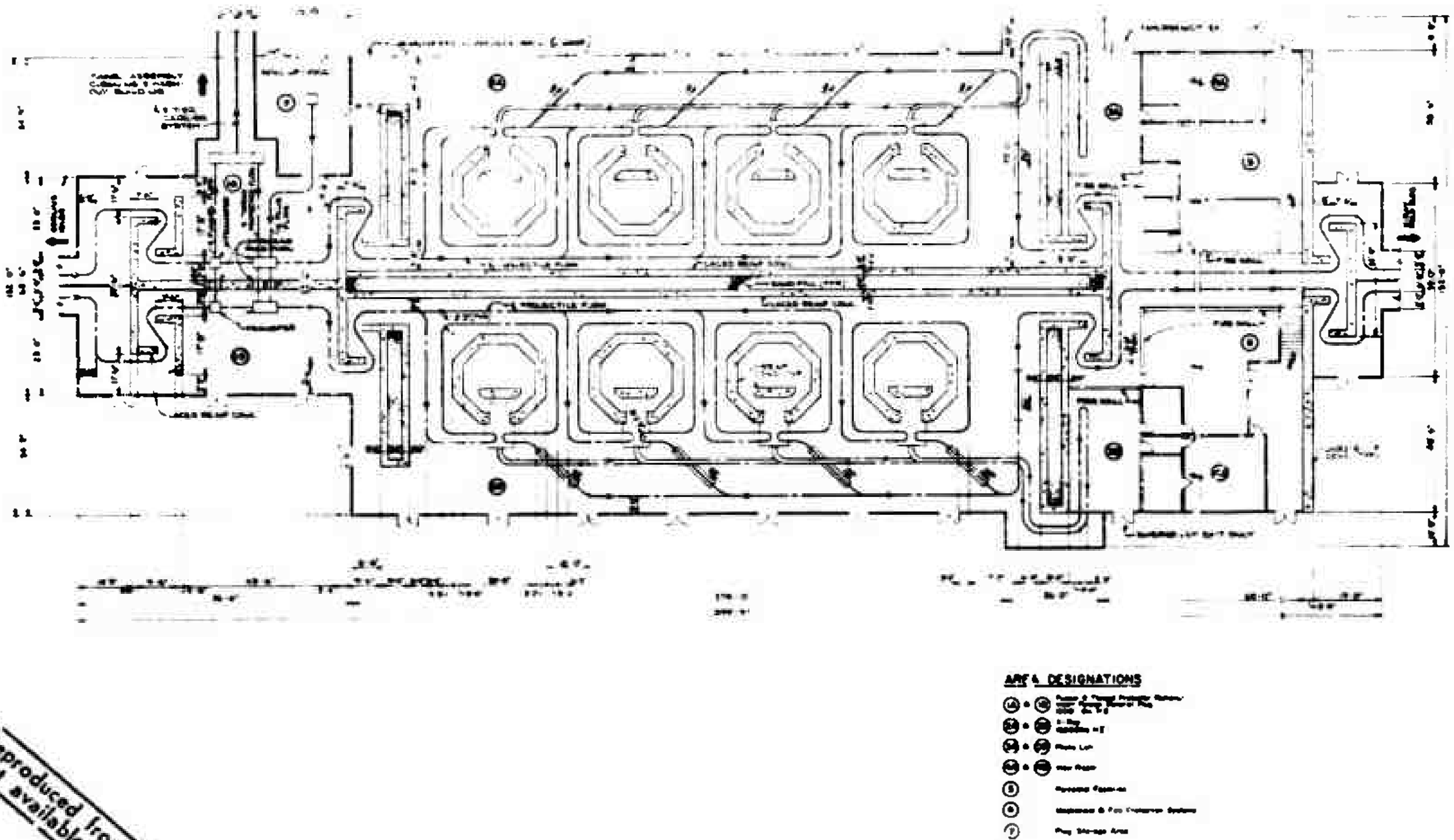

FIG. 16 PRE – ASSEMBLY BUILDING

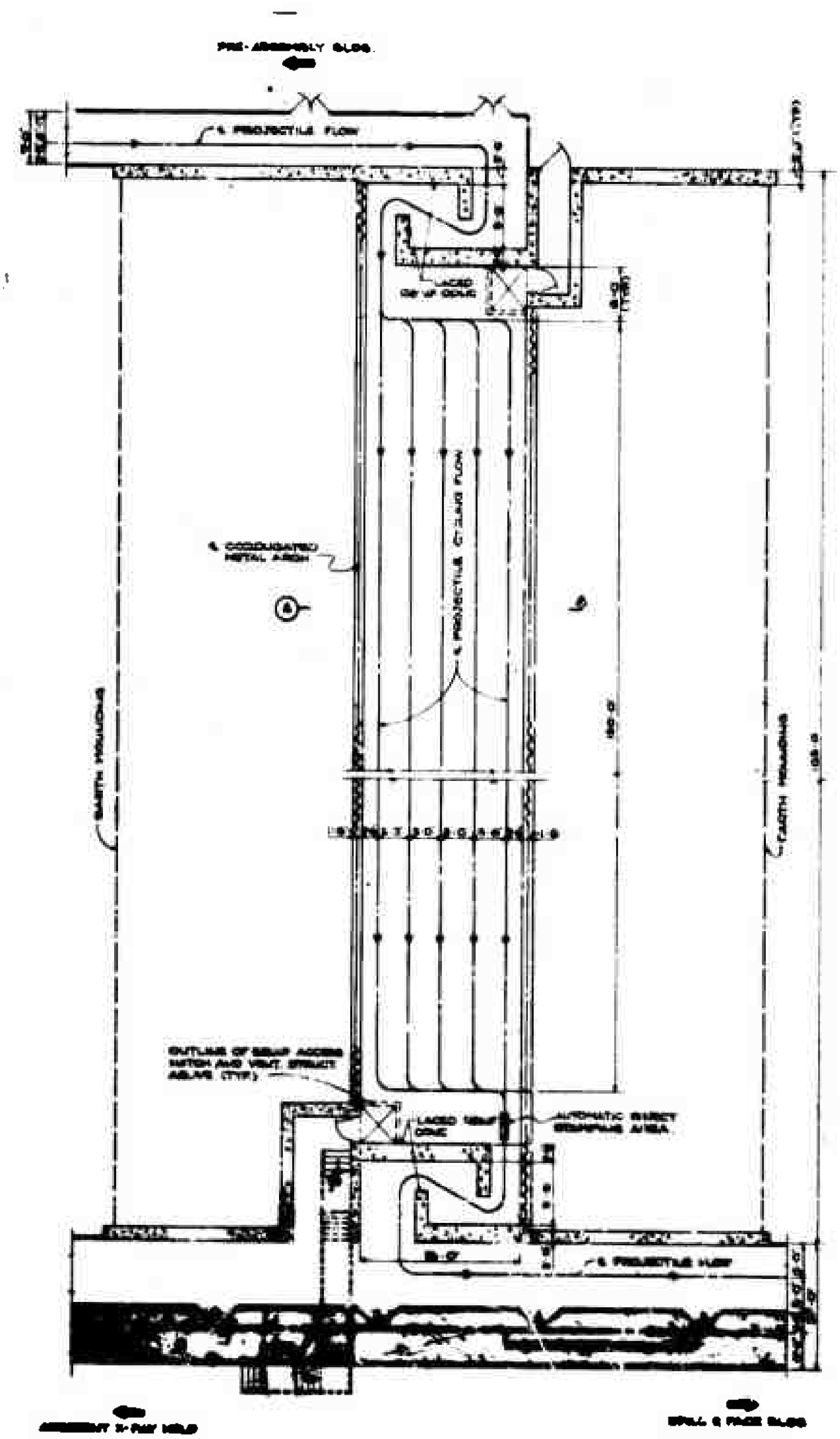

FIG. 17 X-RAY HOLD BUILDING

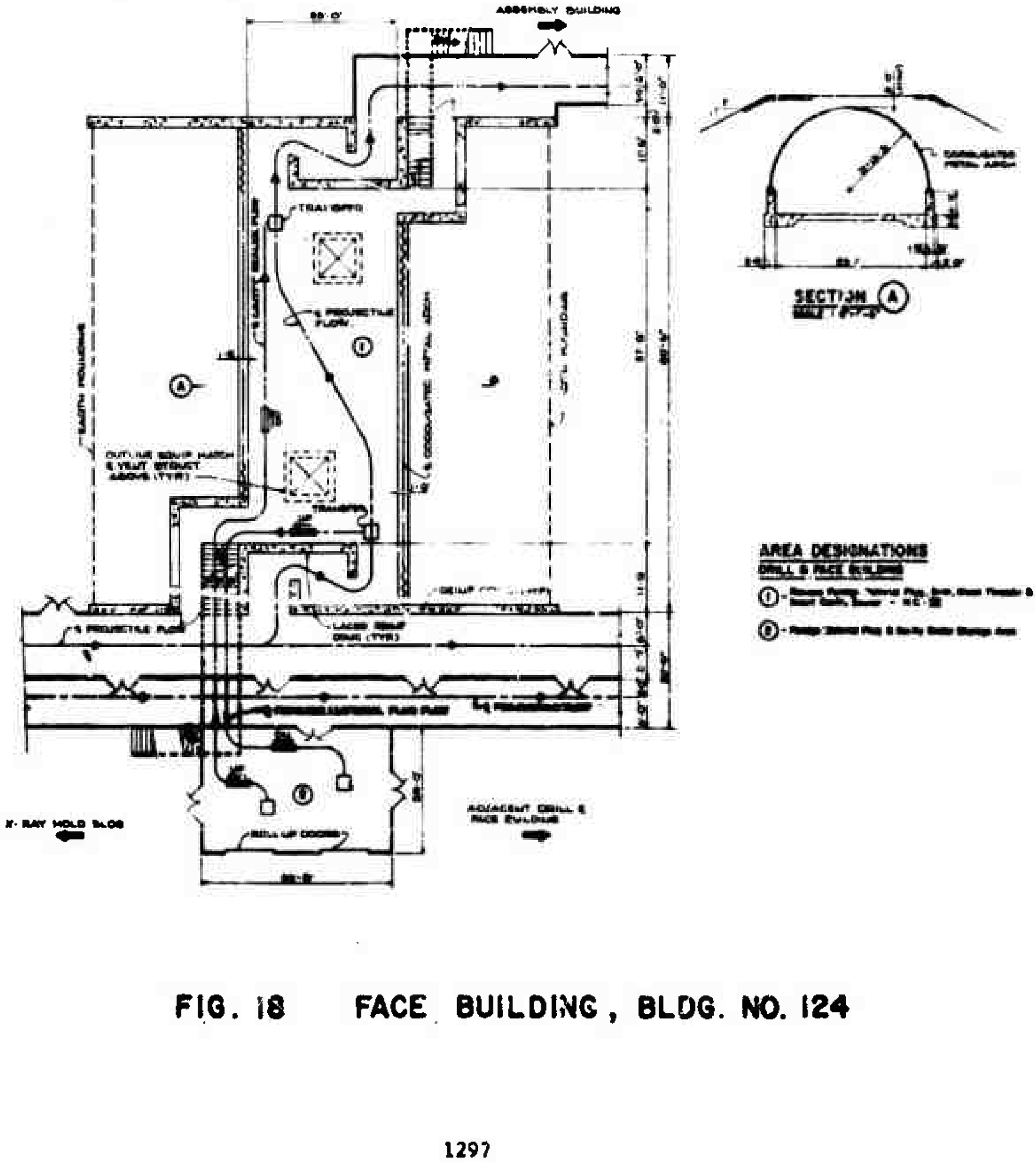

FIG. 18 FACE BUILDING, BLDG. NO. 124

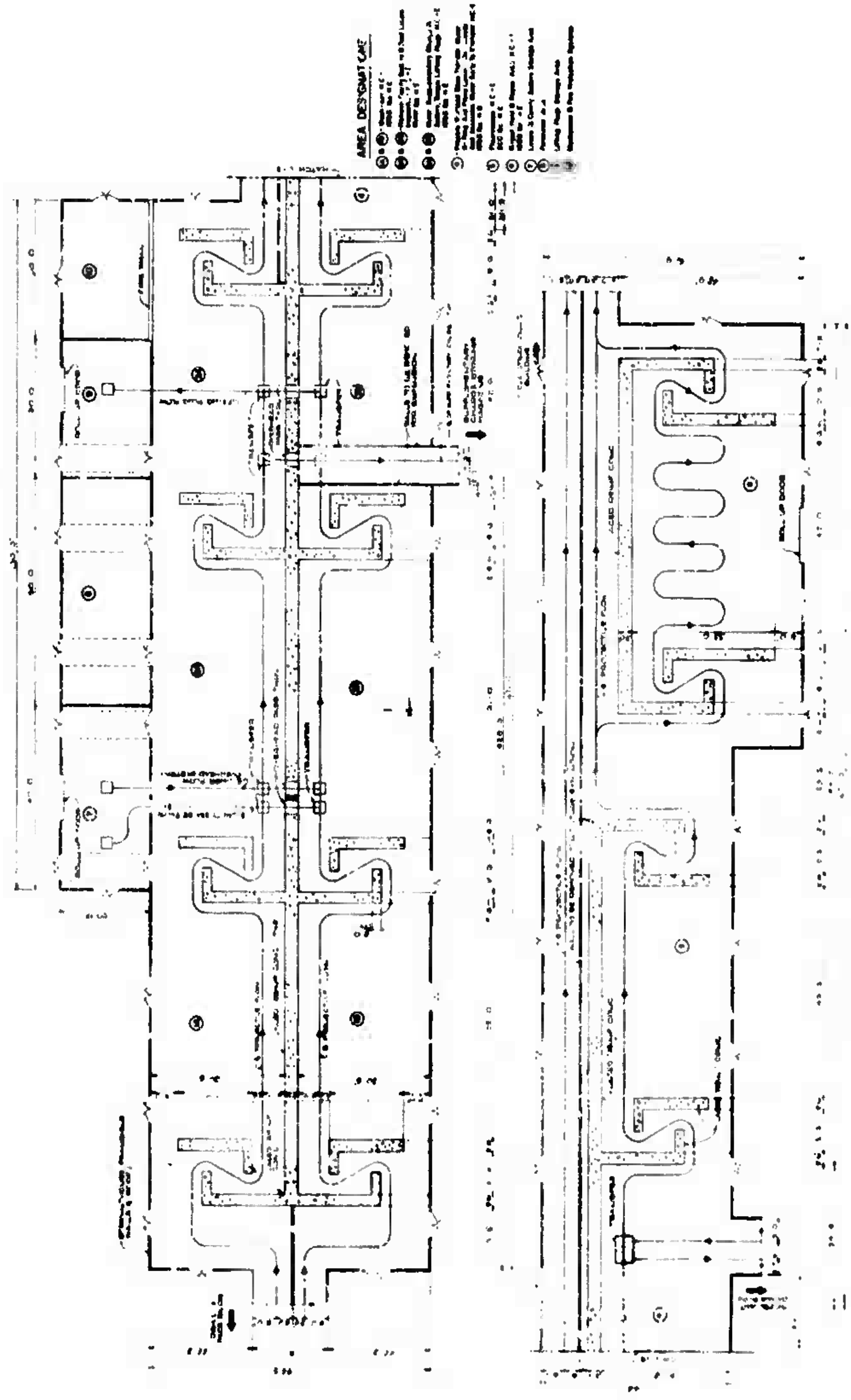

FIG. 19 ASSEMBLY BUILDING, BLDG. 127

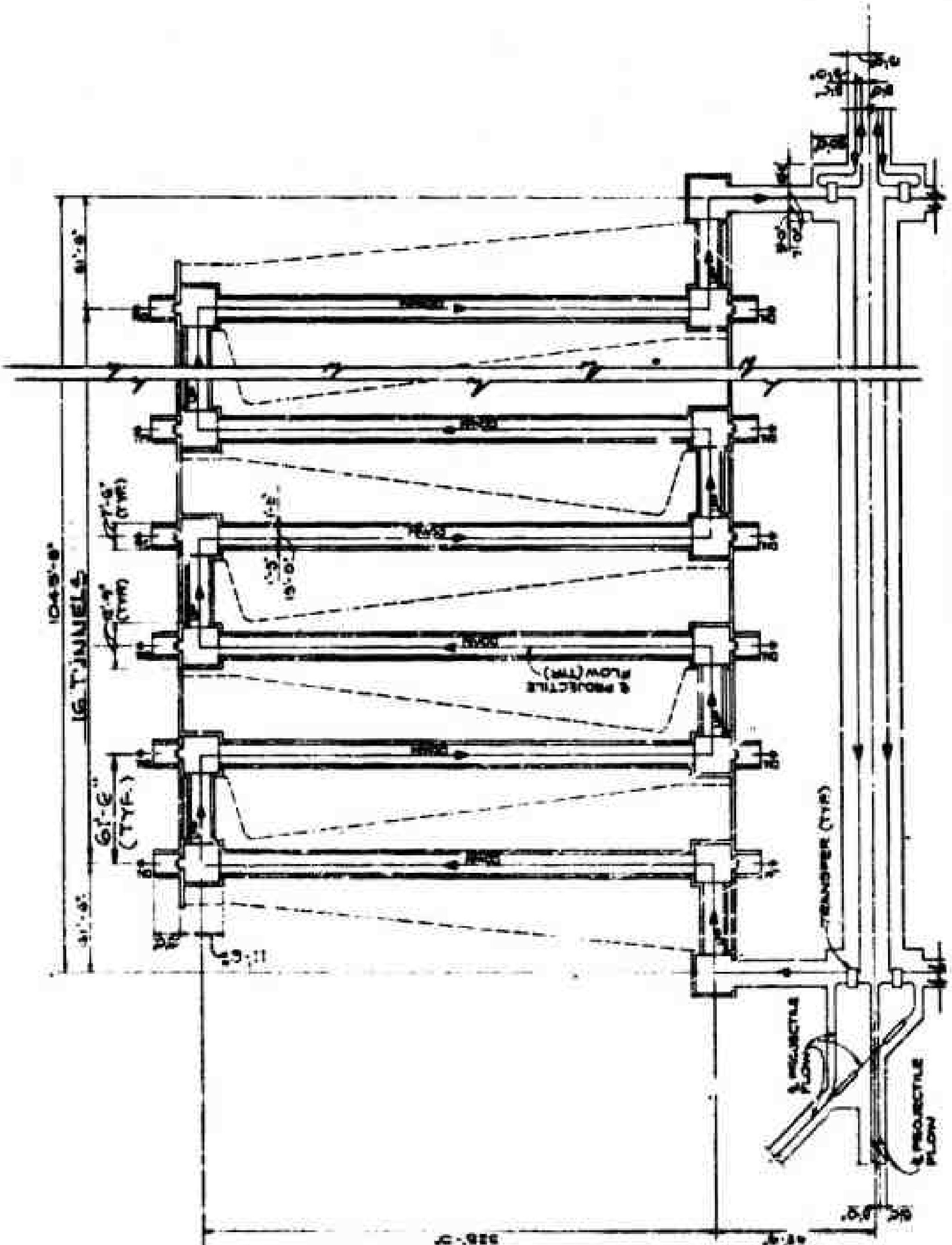

FIG. 20 CYCLIC CONDITIONING BUILDING, BLDG. 135

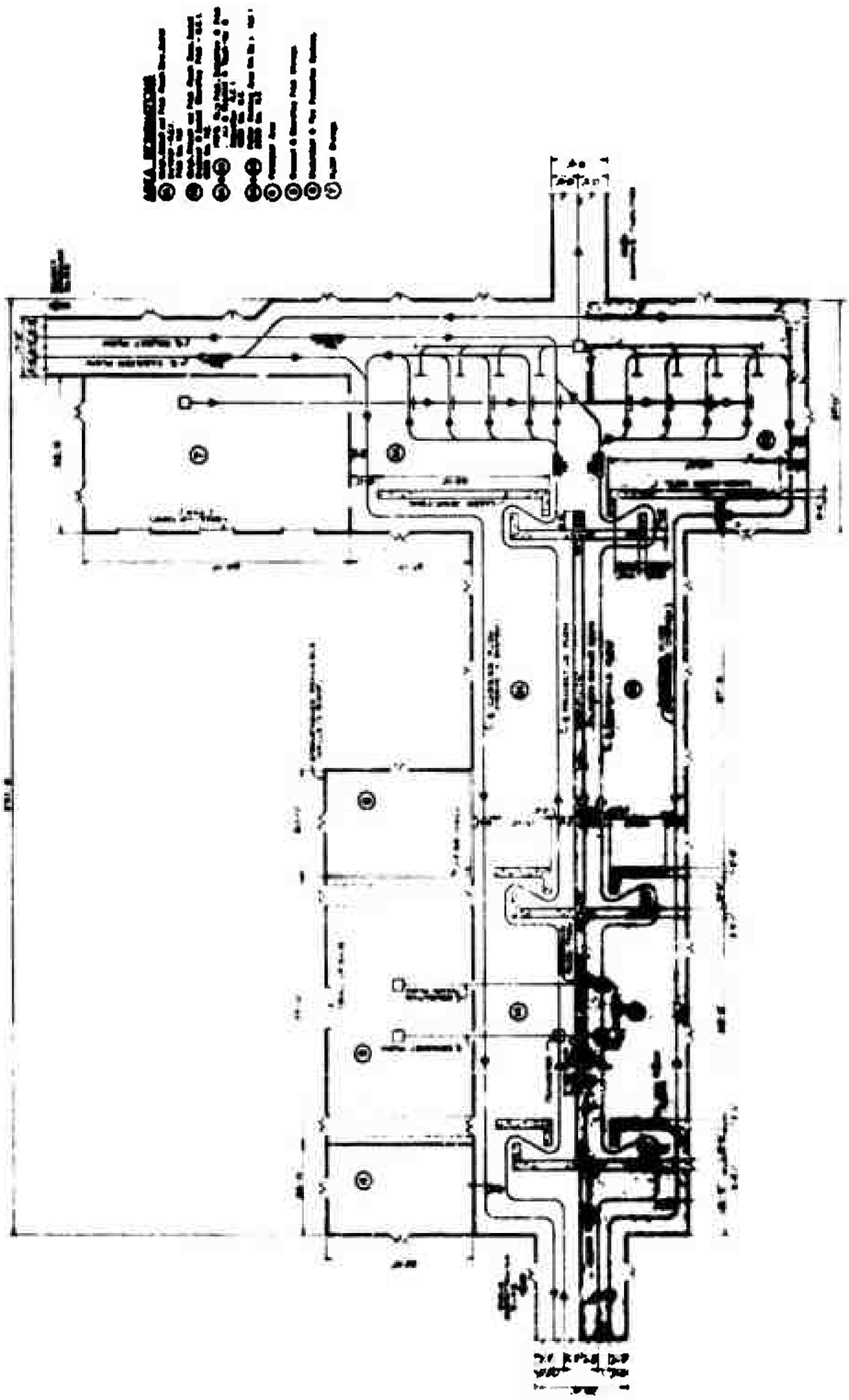

FIG. 21 PACK-OUT BUILDING, BLDG. NO. 138

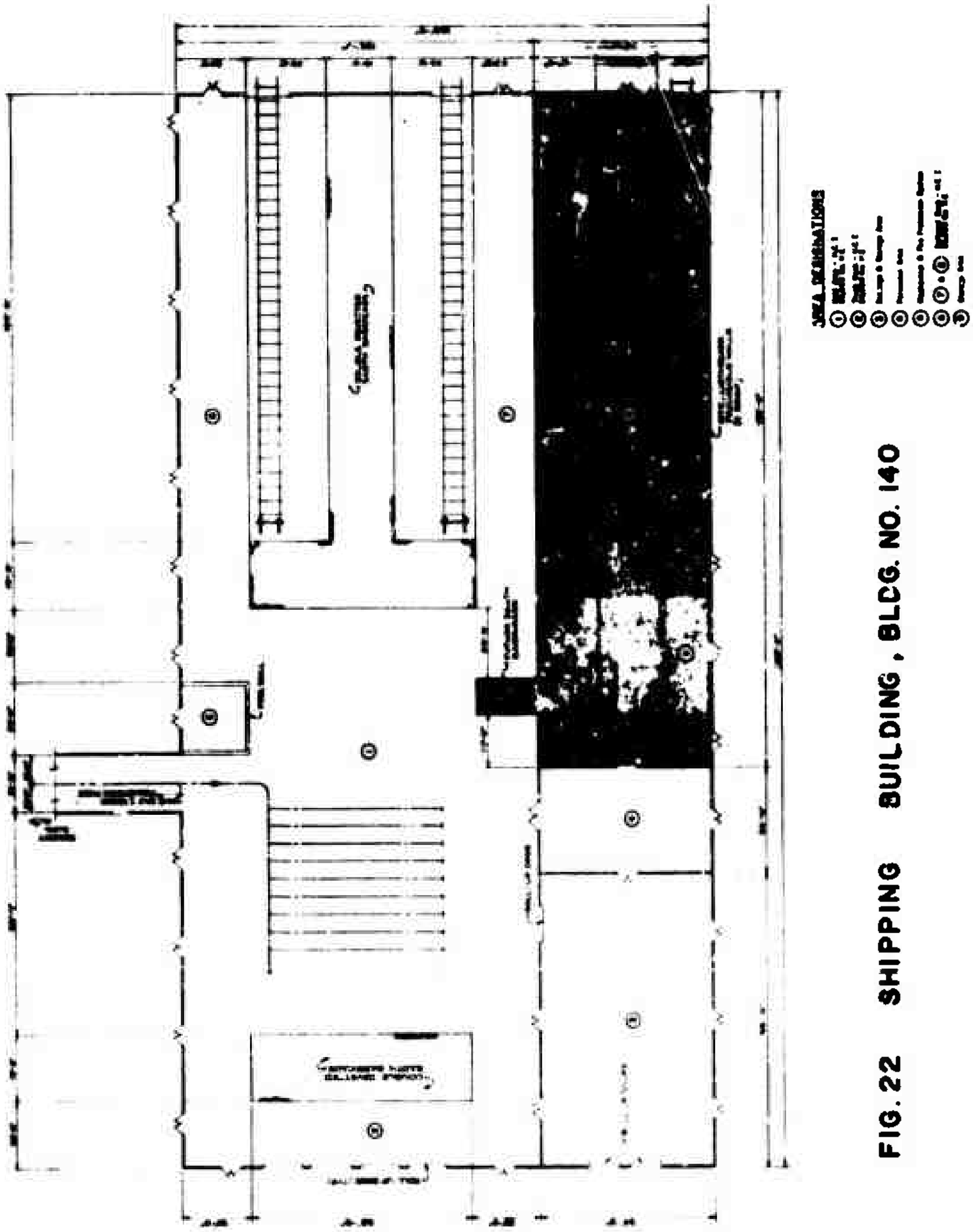

FIG. 22 SHIPPING BUILDING, BLDG. NO. 140

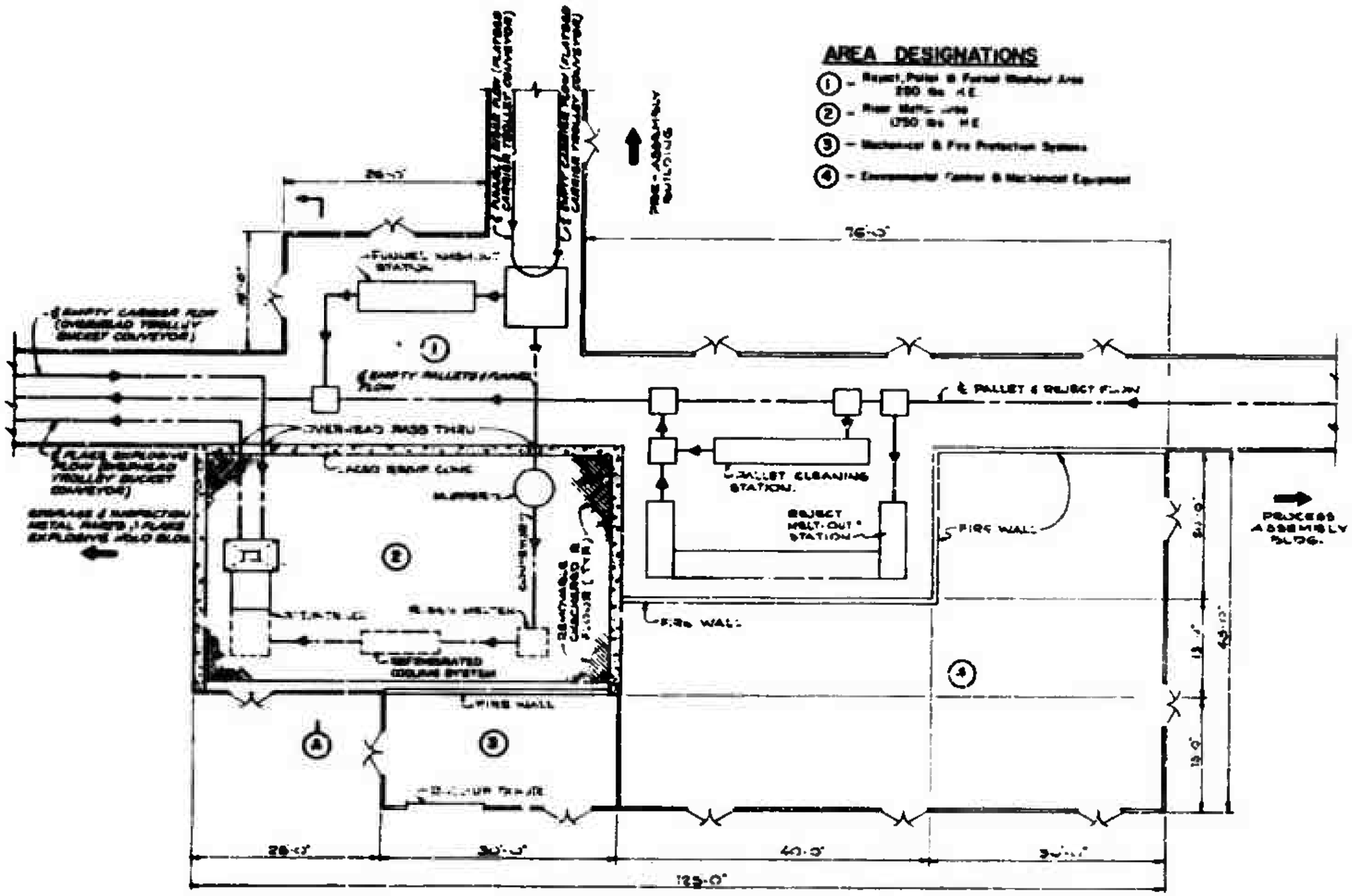

FIG. 23 WASHOUT & RISER MELTER BUILDING, BLDG. NO. 121

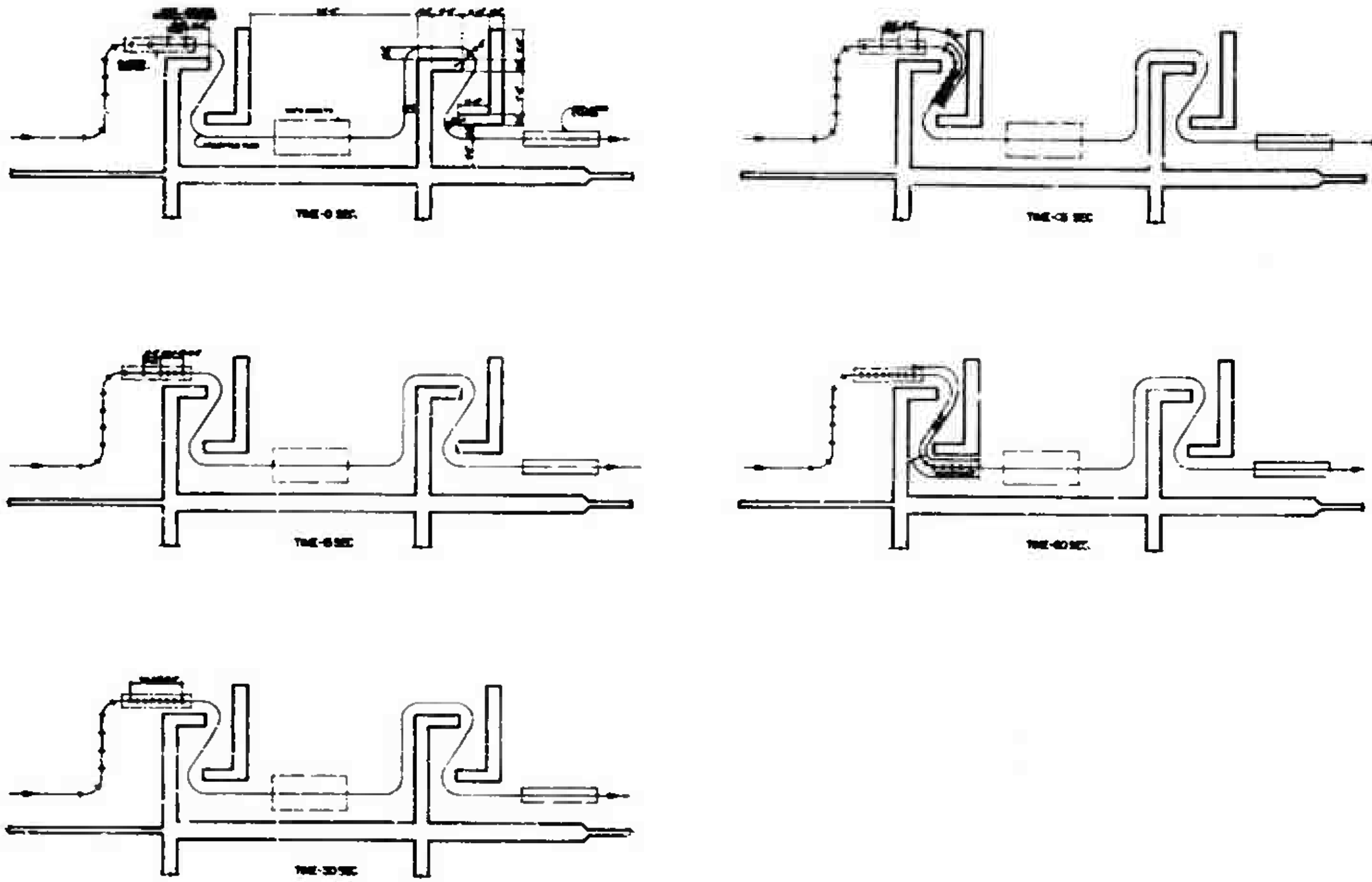

FIG. 24 TRANSFER OF ITEMS THRU BUILDING

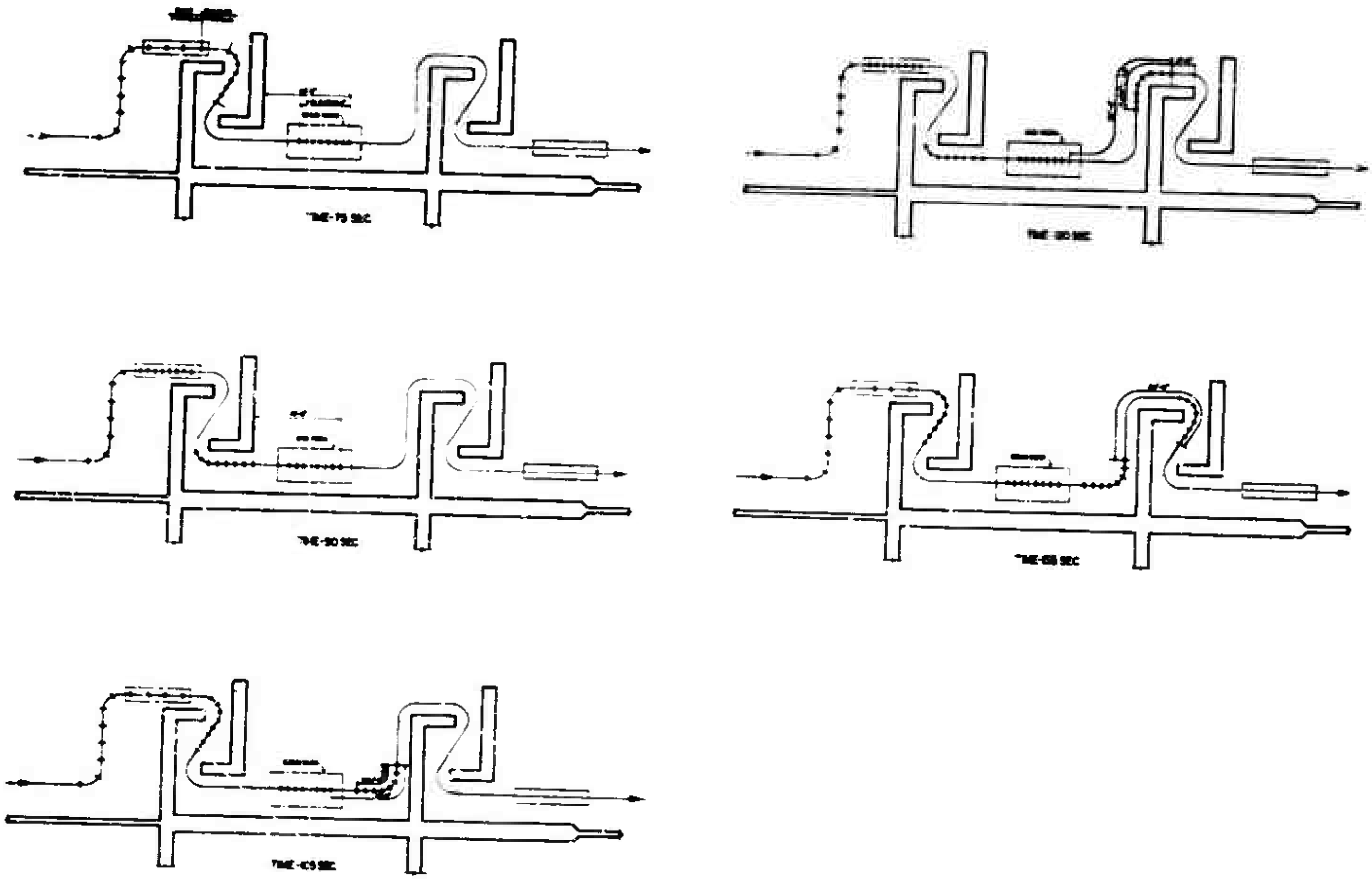

FIG. 25 TRANSFER OF ITEMS THRU BUILDING

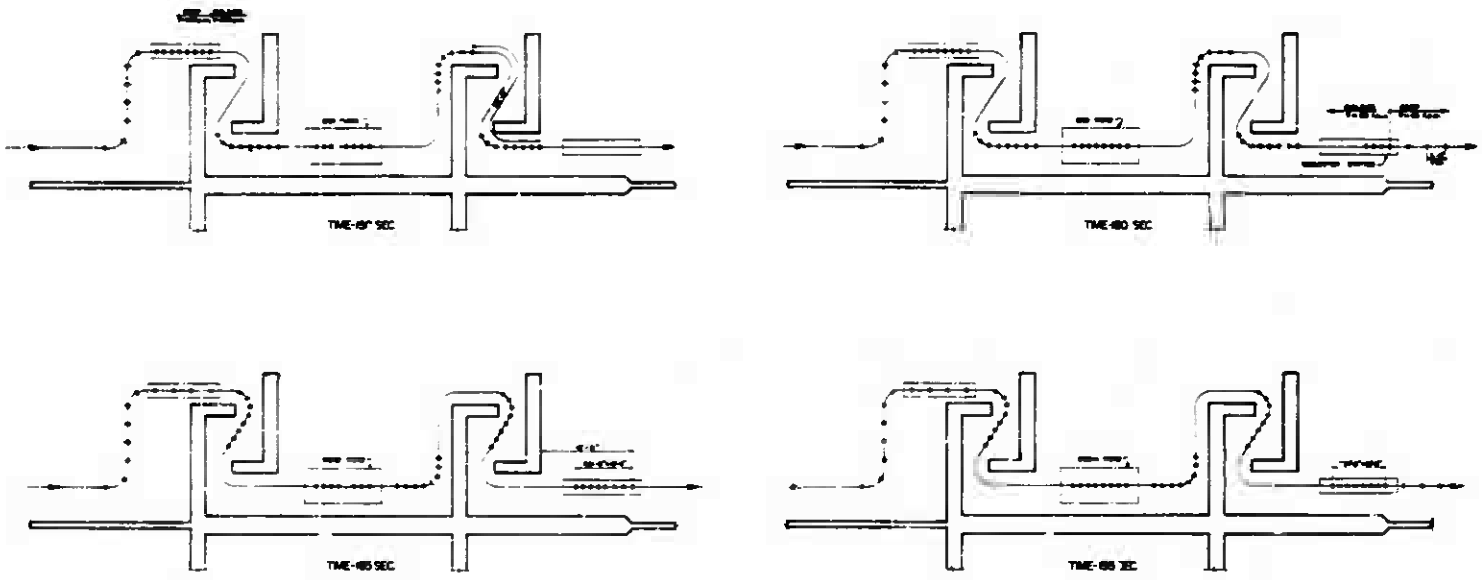

FIG. 26 TRANSFER OF ITEMS THRU BUILDING

BARRIER WALLS TO DEFEAT SHELL FRAGMENTS

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Vicksburg, Mississippi

1. INTRODUCTION

1.1 BACKGROUND. For the past several years the Weapons Effects Laboratory of the Waterways Experiment Station (WES) has been engaged in research to develop structures to protect personnel and equipment from the blast effects of nuclear weapons and the penetration, blast and fragmentation effects of non-nuclear weapons. The information presented in this paper was derived from an overall program to develop structures to protect parked Army aircraft (primarily helicopters) from the effects of indirect fire weapons (rockets and mortars). The aircraft shelters study was divided into two separate problems (Figure 1). The first problem worked was that of developing barriers to defeat the blast and fragmentation effects of "near misses." The second problem was to develop deliberate covered shelters to defeat the effects of a direct hit.

1.2 OBJECTIVE. Today the results of research conducted on materials and barriers to determine their effectiveness for defeating shell fragments and blast effects will be presented. Although the barriers were developed primarily to provide protection for parked Army aircraft, they would also be useful around other types of critical supplies or equipment.

1.3 SCOPE. In the course of developing the prototype barriers, several intermediate steps were necessary. First, possible candidate materials were selected and their fragment defeating properties determined by fragment simulation tests which were conducted in the laboratory. The

most promising materials and materials systems, as determined by the laboratory tests, were then subjected to the blast and fragmentation effects of actual weapons during a series of field tests. Fragment characteristics such as size, velocity, spatial distribution, and penetration were concurrently collected during the field tests. Finally, barrier structures, which evolved from the field test on the materials, were constructed and tested.

2. FRAGMENT SIMULATION TESTS

2.1 OBJECTIVE. The objective of the fragment simulation phase of the test program was to select and evaluate available materials for fragment barrier application. Emphasis was placed on materials which were field available and suitable for construction elements.

2.2 EQUIPMENT. The equipment used for fragment simulation tests was housed in the underground firing range and an instrumentation support building shown in Figure 2. The fragment-simulation projectile is fired from the gun shown in the figure through the two light beam chronograph screens and impacts the sample under test. If the projectile penetrates the sample, its exit velocity is measured with the output of the reor chronograph screens. The fragments or fragment-simulating projectile is transported down the barrel in a plastic carrier or sabot. The velocity of the projectile varies with the initial powder charge. Most of the work at WES has been done with a 21-grain steel cube at velocities of up to 5000 feet per second or with a 303-grain steel cylindrical projectile at velocities of up to 2700 feet per second.

2.3 MATERIALS CONSIDERED. Materials evaluated in the Fragment Simulation Facility include ballistic nylon fabrics and felt, fiberglass-reinforced plastics, landing mats, timbers, portland cement concrete, asphaltic concrete, sand and clay soils, and a small number of proprietary items.

2.4 RESULTS.

2.4.1 Ballistic Nylon. At the start of this study a great deal of interest was shown by the sponsor in the use of ballistic nylon fragment blankets to form portable, crew-erectable barriers. The material used would be similar to the old type "flack vests." Both nylon cloths and felt of various thicknesses and applications were evaluated. The nylon material was not recommended because it was not effective in stopping high-velocity fragments.

The failure mechanism of ballistic nylon is such that the material is not a suitable protection candidate for the barriers. Nylon is an effective material for stopping low velocity bullets and fragments since it can absorb the kinetic energy by the elongation of the high tensile strength fibers. However, if the impact velocity of the particle is sufficiently high, the filament will not have time to respond in tension but will fail in shear instead. The critical velocity is therefore defined as the minimum velocity at which the filament shears immediately upon impact (Figure 3). Unfortunately, the velocity of most of the fragments from the munitions later tested exceeded the critical velocity point.

2.4.2 Soils (Sand and Clays). Tests were conducted to determine the response of both dry and saturated sand and clay to high velocity fragments. The soil samples were contained in 1-, by 1-, by 1-foot plywood boxes. The sand, either wet or dry, proved highly resistant to penetration by the 21-grain cube. An illustration of the effectiveness of the sand at stopping fragments and the tendency of the projectile to reach a maximum depth of penetration at velocities of approximately 3000 and 3500 feet per second in dry and wet sand is shown in Figure 4, respectively. Velocities greater than 3500 feet per second do not yield increased penetration.

Although the basic reasons for the interesting response of soil to fragment impact are being determined by the Soils and Pavements Laboratory of WES, the practical fact learned from the tests reported here was that none of the fragment-simulating projectiles penetrated 1 foot in the soils tested.

3. FIELD TESTS - MATERIALS AND WEAPONS EFFECTS

3.1 OBJECTIVE. The purpose of these field tests was to determine the response of materials systems to the blast and fragmentation effects from actual rounds and further to define fragment size, distribution, penetration and velocity characteristics for the munitions and ranges of interest.

3.2 MUNITIONS USED. The U. S. fragmentation shells utilized included 81-mm (M374) and 4.2-inch (M329) mortars. Tests were also conducted with Soviet 82-mm mortars (M832D) and 122-mm (model unknown) spin-stabilized

rocket fragmentation rounds. The Chinese Communists' 82-mm (M30) And 120-mm (model unknown) mortars and 107-mm (model unknown) spin-stabilized rocket rounds were also used (Figure 5).

3.3 TEST GEOMETRY. Typical samples in the test arena included a large witness board, various material samples, fragmentation screens, and celotex-filled boxes to trap fragments for size and velocity (Figure 6). All test rounds were positioned nose down in contact with the test bed and statically detonated. The majority of the tests was conducted on an M8A1 landing mat paved surface.

3.4 RESULTS.

3.4.1 Landing Mat. It was found that a single piece of M8A1 steel landing mat (1/8-inch-thick mild steel) stopped a significant number of fragments; it was also noted that those fragments which penetrated were broken up, their trajectory altered, and their velocity reduced. If a second wall of mat is placed behind the front, most of the remaining fragments were defeated.

Two configurations of double-layered M8A1 samples were tested. One consisted of two panels attached together at the top to form an A-shaped structure. The second configuration used the mat to form parallel vertical walls separated by a distance of one foot (Figure 7).

3.4.2 Soil Bins. Soil bins constructed with walls of 3/8-inch-thick plywood, 26-gage corrugated steel, and M8A1 landing mat were filled with 6 inches of a clayey sand and tested at various ranges from the

rocket and mortar rounds. Results of the field tests indicated that all fragments from detonations as close as 30 feet were defeated by the soil bins (Figures 8 and 9).

3.4.3 Fragment Distribution. Fragment patterns for each of the rounds tested were recorded on a 20- by 60-foot witness board. Typical fragment patterns from an 81-mm and a 4.2-inch mortar round detonated 50 feet from the witness board are shown in Figure 10. The outline of a UH-1 series helicopter was superimposed on this pattern along with the projected protection limit that would be provided by a 5-foot-high barrier which is located a distance of 10 feet from the helicopter.

4. FIELD TESTS - PROTOTYPE BARRIERS

4.1 OBJECTIVE. The purpose of this field test was to evaluate prototype thin earth-filled barriers (12 inches thick) constructed with walls of plywood, corrugated metal, and M8A1 landing mat. Two types of structures were tested as described below.

4.1.1 Free-Standing Barriers. These structures, constructed of timber and plywood or corrugated metal, were designed primarily for temporary use around utility or attack helicopters or small equipment. They were 12 inches thick, 5.5 feet high, and built in 8-foot-long modules. Both barriers defeated the blast and fragment effects of 82-, 107-, and 120-mm rounds at a structure-to-round distance of 5 feet. However, it was determined that unless they were braced or anchored, the blast from the

4.2-inch mortar and 122-mm rocket would cause overturning at a distance of 10 feet. Damage caused by typical rounds is shown in Figures 11-13.

4.1.2 Post-Supported Barriers. These larger structures were designed mainly for cargo-type helicopters or large equipment. These barriers were 12 inches thick, 12 feet high, and built in 24-foot-~~high~~ sections. Plywood, corrugated metal, or M8A1 landing mat was used for the walls. Each barrier was supported by 6- by 12-inch timber posts set in the ground or embedded in concrete. The post-supported structures defeated the effects of all threats tested at a structure-to-round distance of 5 feet. Figures 14-17 show typical damage.

5. SUMMARY OF BARRIERS CURRENTLY IN USE

The thin-walled barriers developed and evaluated at WES have been included in the recent revisions of Army field manuals. In addition, many of the M8A1 post-supported structures have been installed in the Republic of Vietnam (RVN) (Figure 18). Some of the units in RVN used the A-shaped M8A1 mat principle to construct a portable barrier. This barrier (Figure 19) was used to close the open end of U-shaped revetments. Another barrier which is extensively used in RVN is a free standing concrete revetment. This barrier (Figure 20) was designed and constructed in the field and is apparently very popular among engineer and aviation units. The barrier features an interlocking footing system which supports a wall panel. The wall unit is usually 6 inches thick, 8 feet long, and available in heights up to 9 feet. Tests conducted by engineer units in the field have shown that the barrier will withstand the blast and fragmentation effects of a 122-mm rocket detonating at 15 feet (Figure 21).

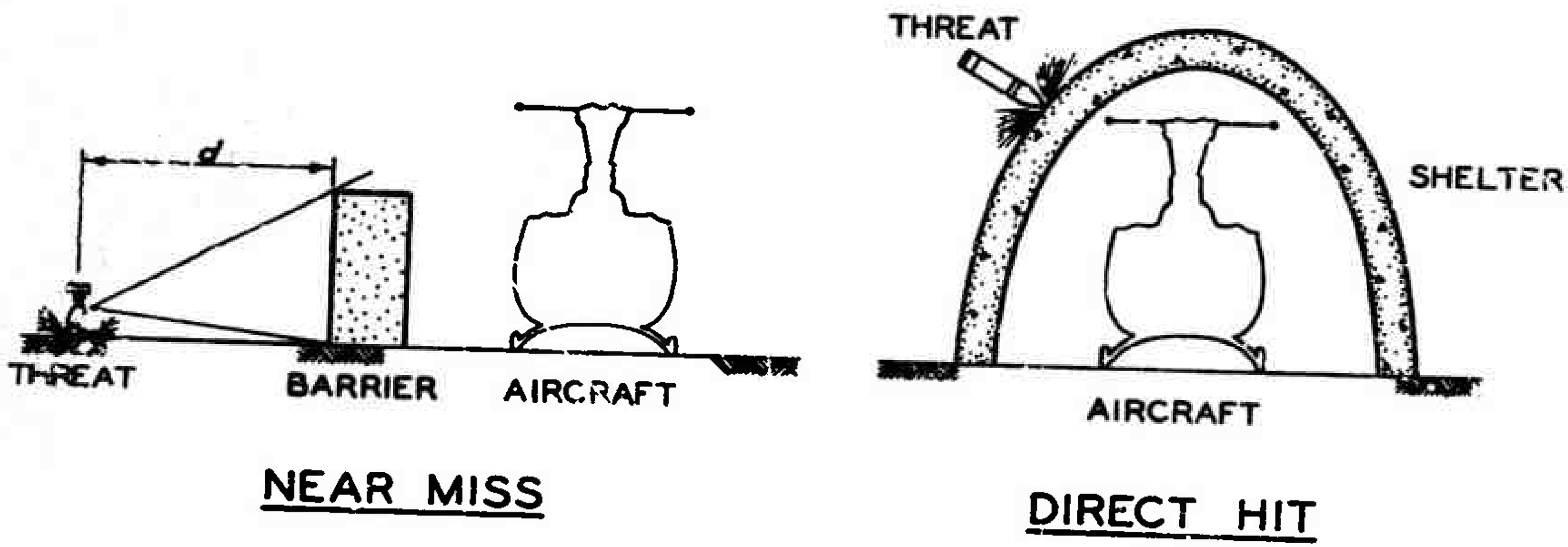
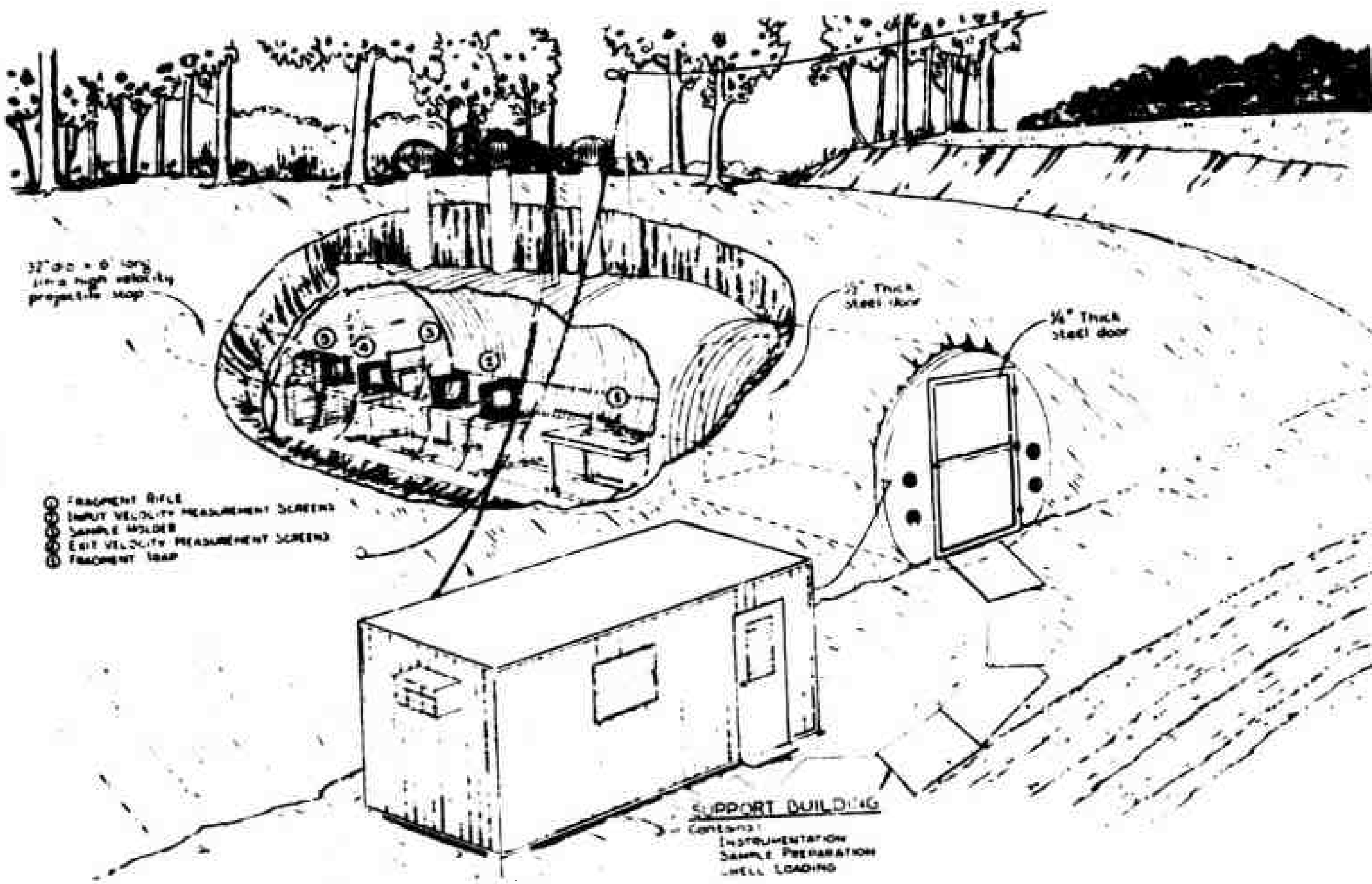
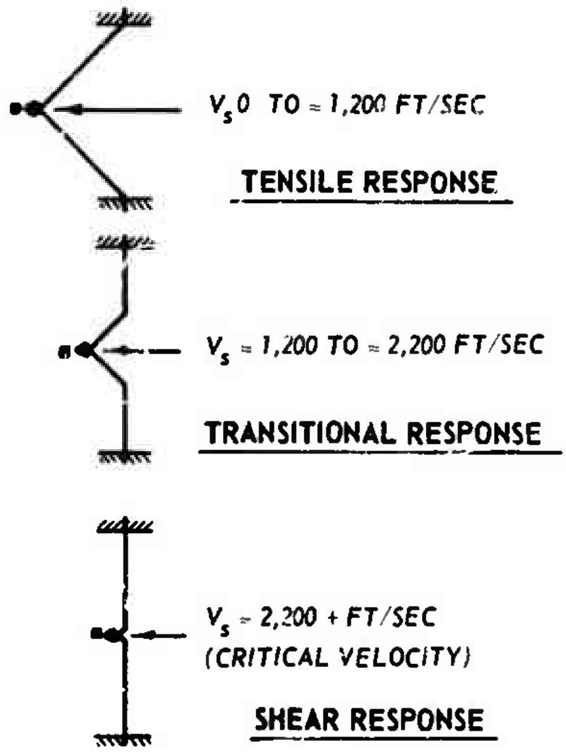


Figure 1 Scope of Aircraft Shelters Program



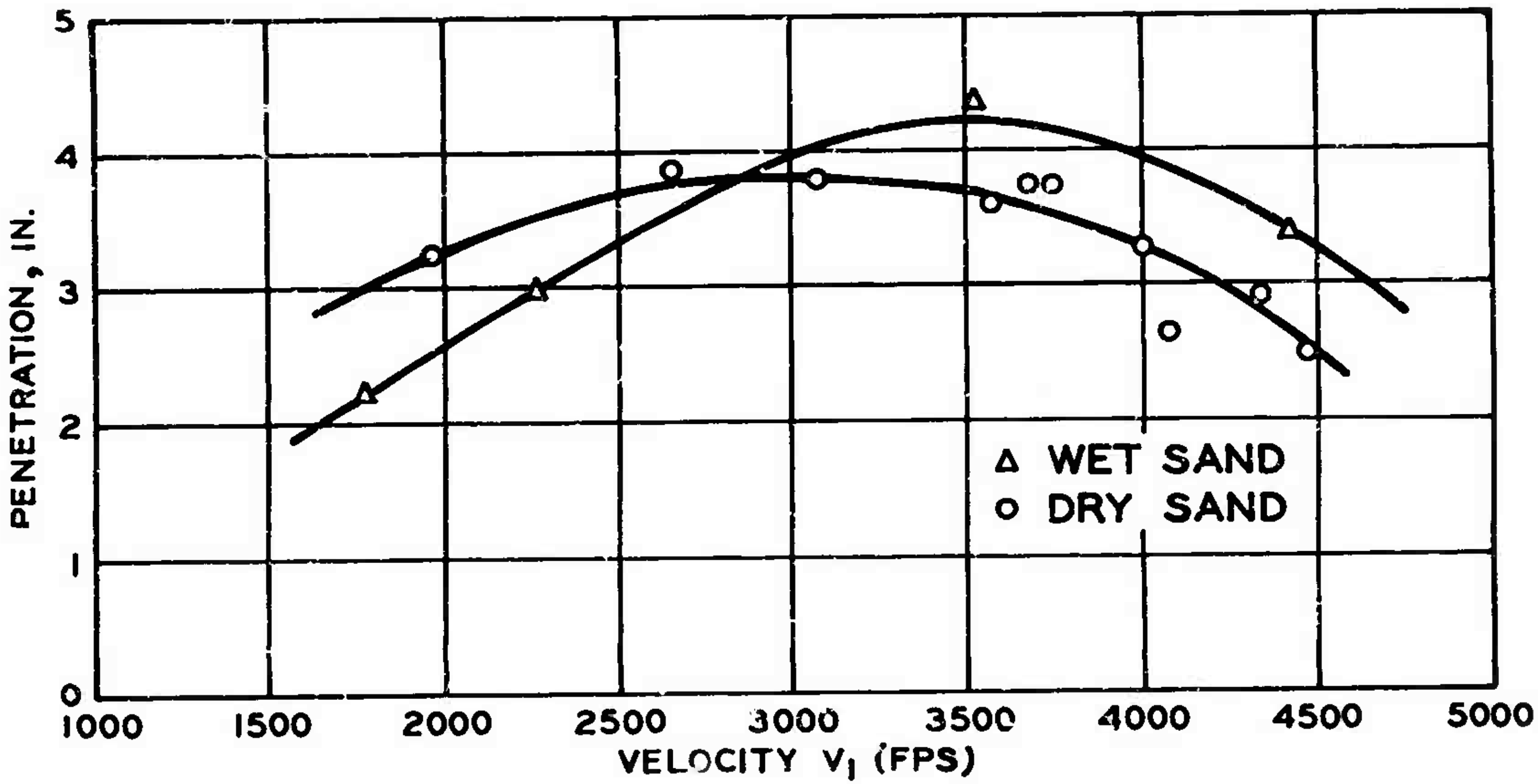
FRAGMENT SIMULATION FACILITY

Figure 2



FAILURE PATTERNS FOR NYLON FILAMENT
(V_s IS STRIKING VELOCITY)

Figure 3



PENETRATION IN SAND OF 21 - GRAIN STEEL CUBE FRAGMENT SIMULATING PROJECTILE

Figure 4

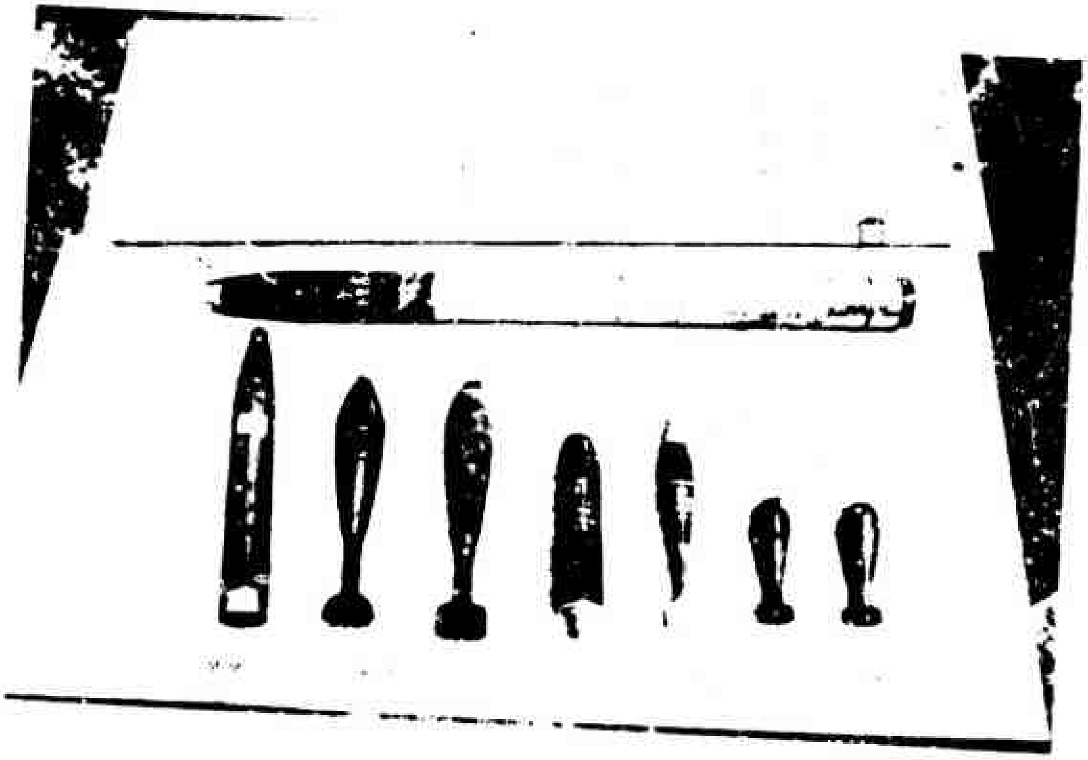


Figure 5

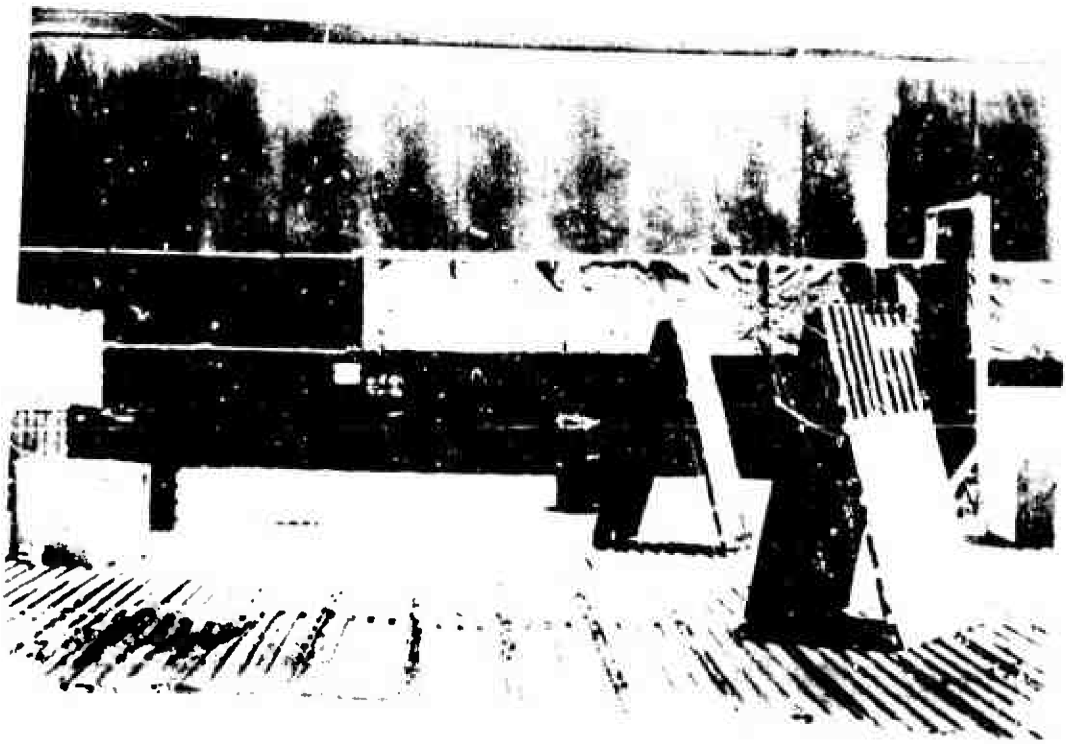
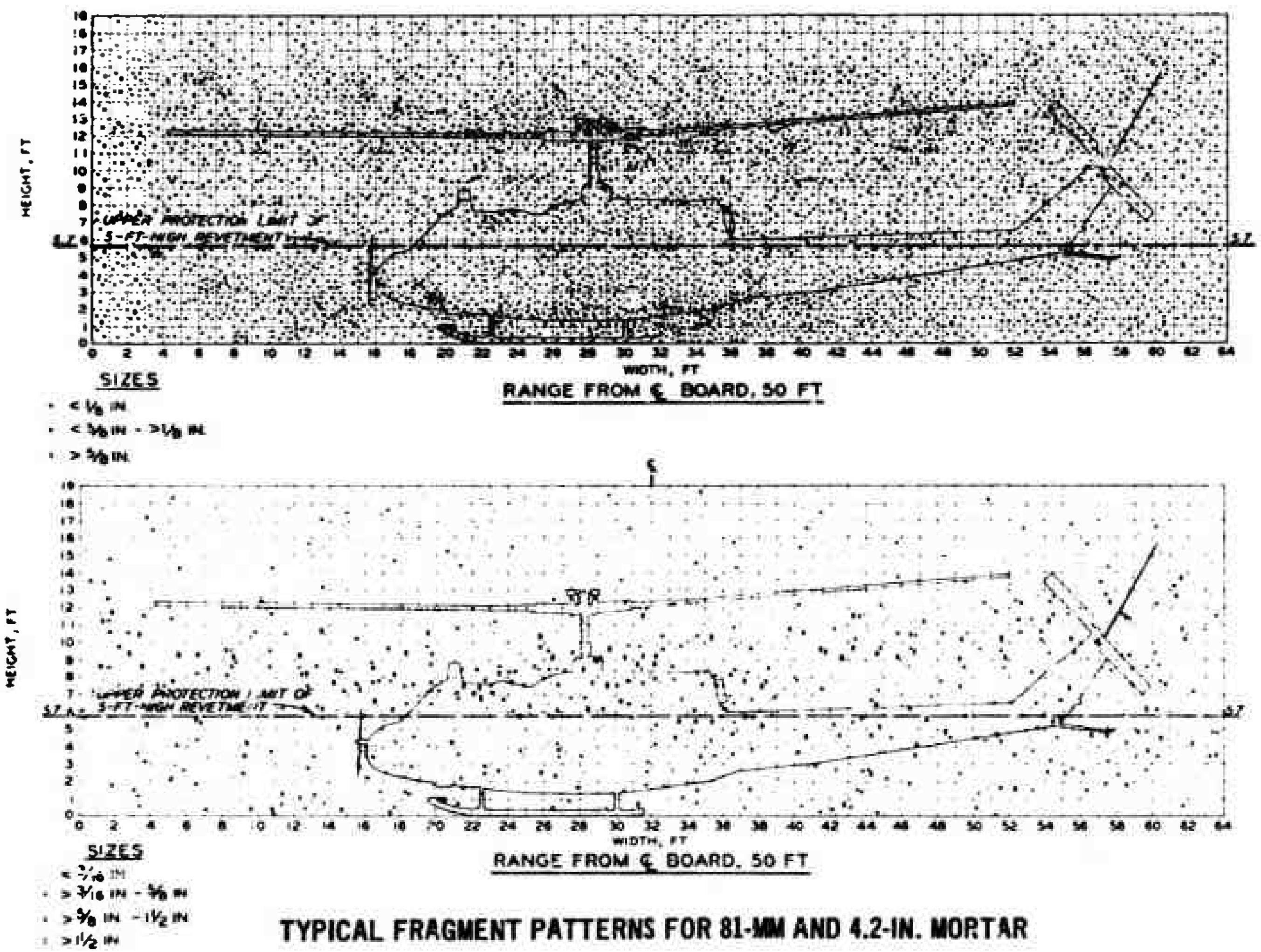


Figure 6

Figure 7

Figure 8

Figure 9



TYPICAL FRAGMENT PATTERNS FOR 81-MM AND 4.2-IN. MORTAR

Figure 10

Figure 11

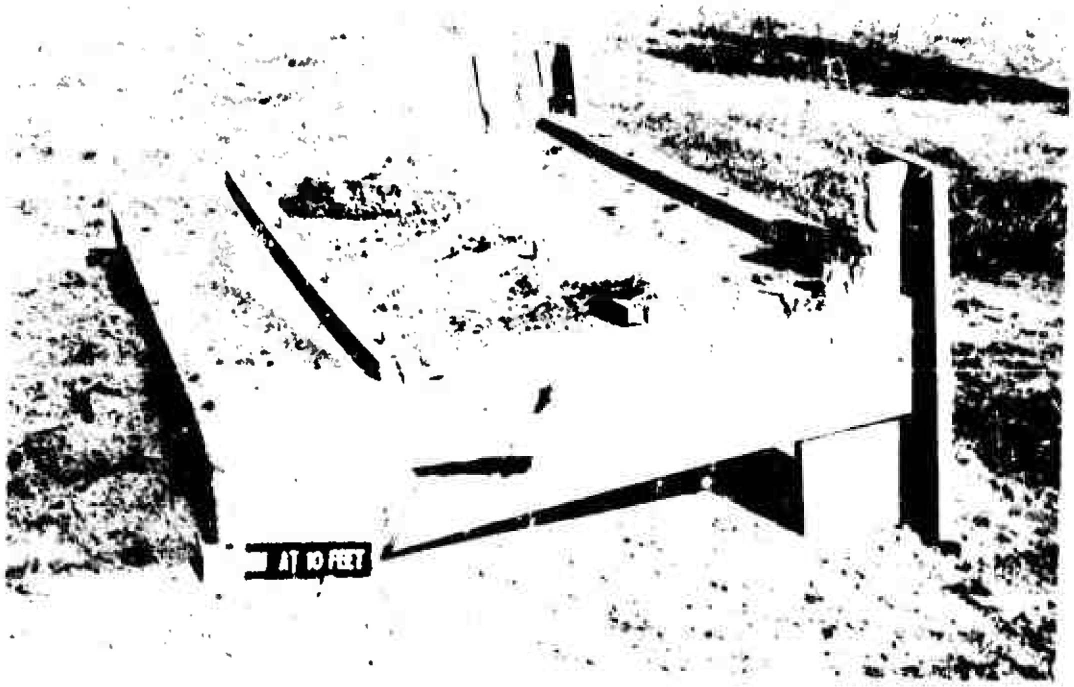


Figure 12

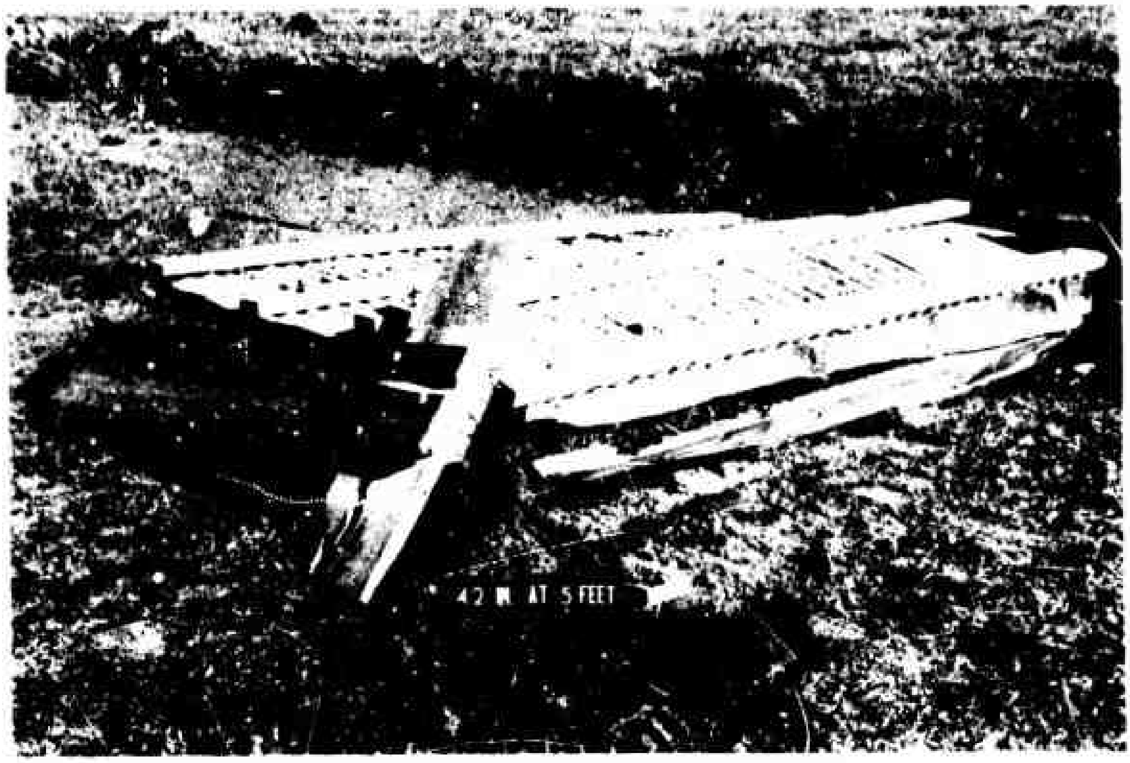


Figure 13

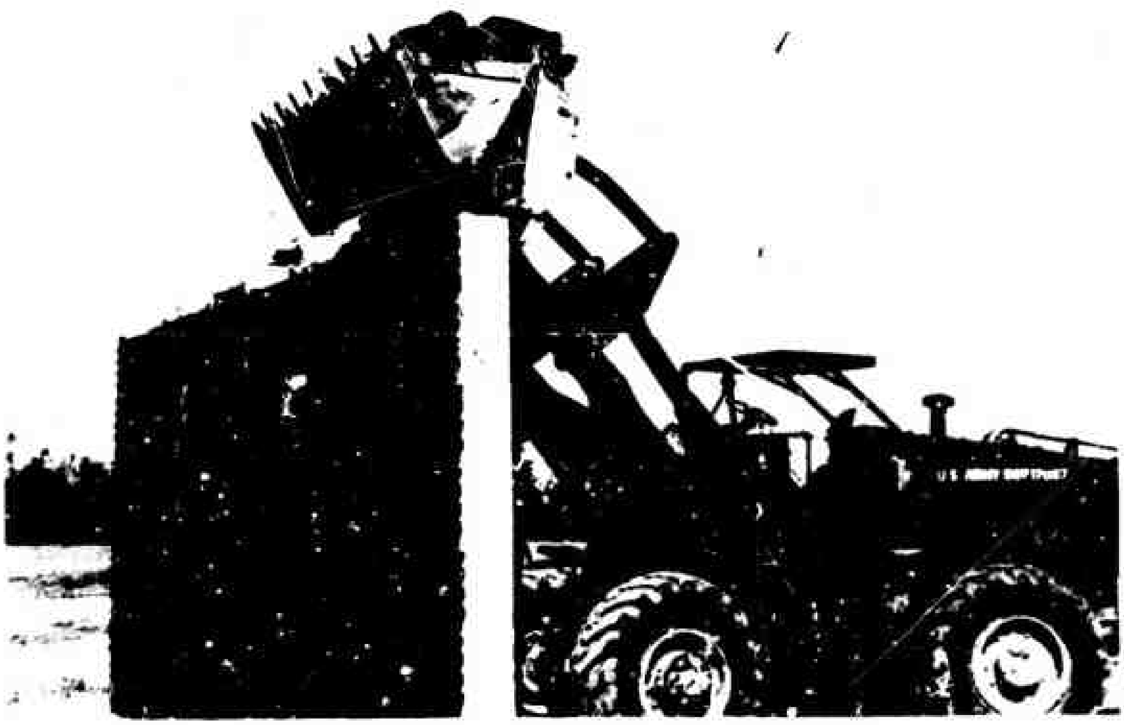


Figure 14

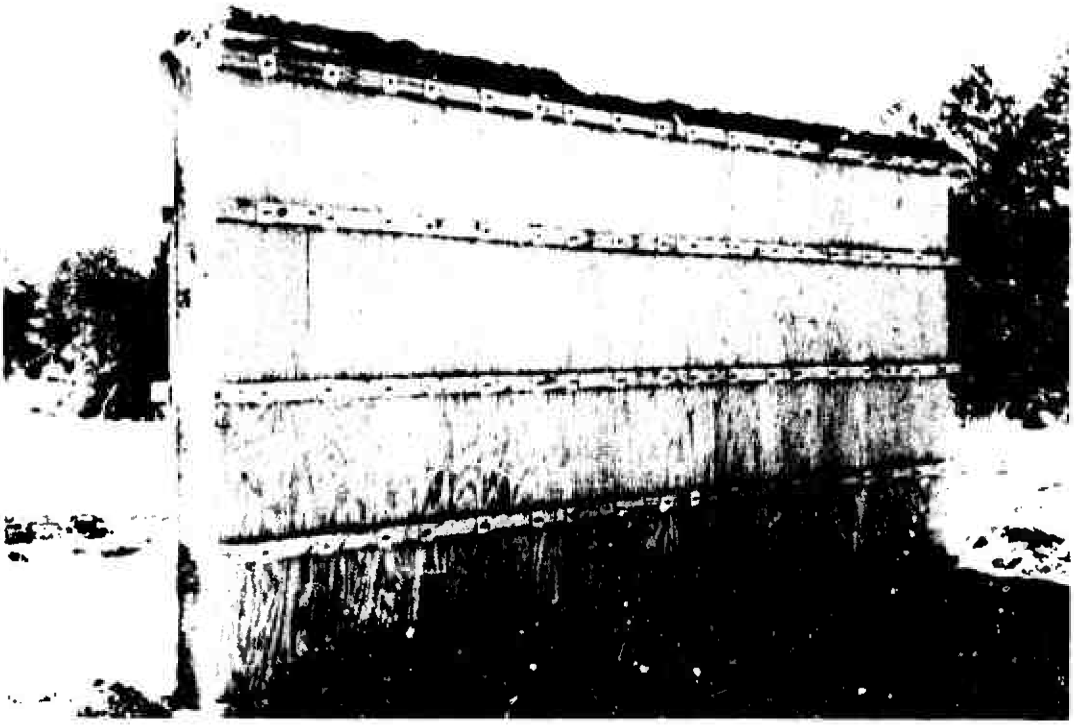


Figure 15

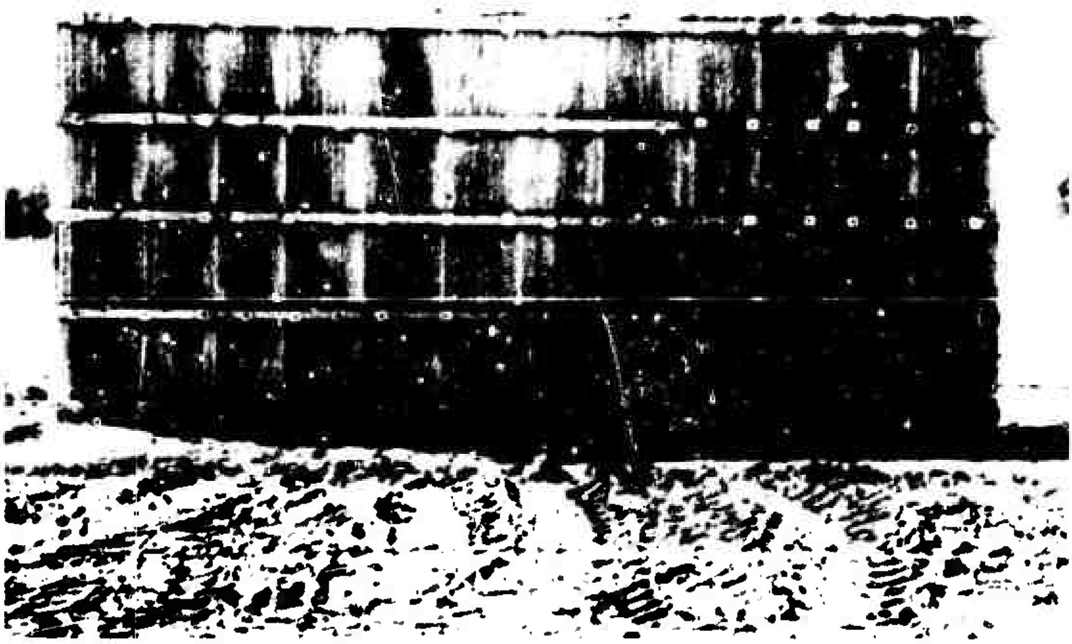


Figure 16

Figure 17

Figure 18

Figure 19

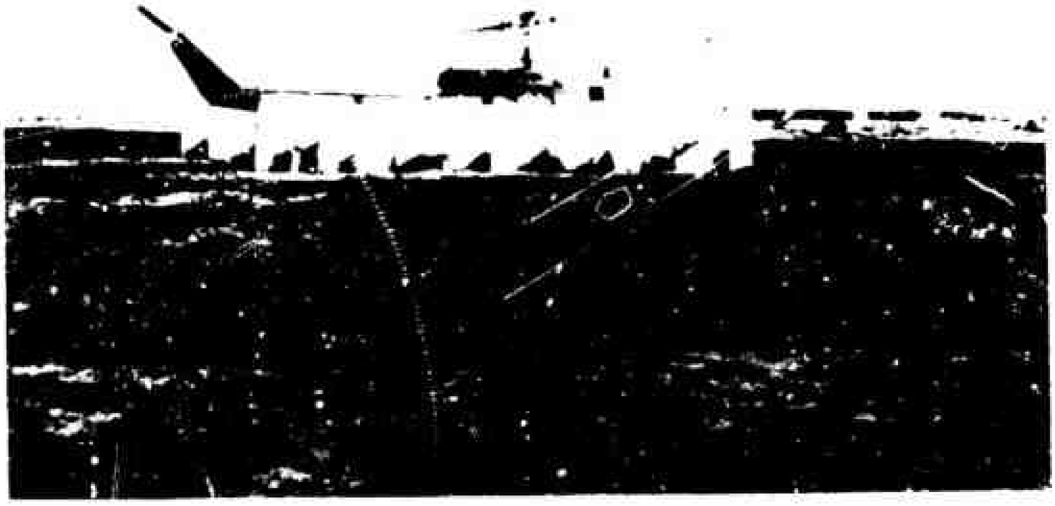


Figure 20

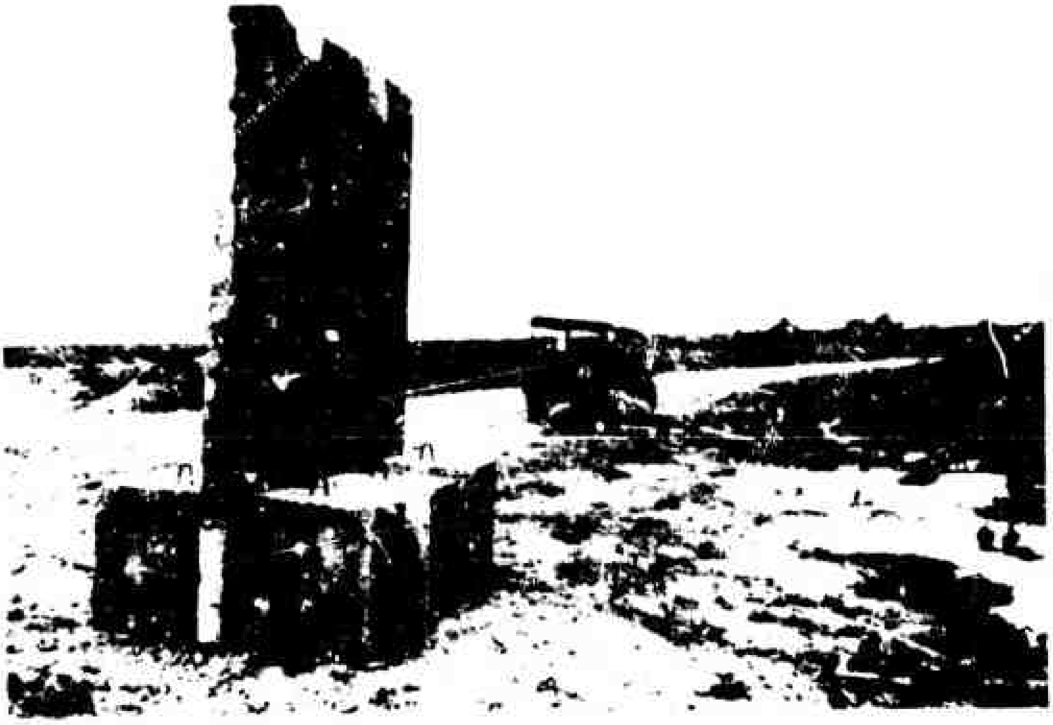


Figure 21

PRELIMINARY ESTIMATE OF CONCRETE THICKNESSES, STRUCTURE CONFIGURATION AND CONSTRUCTION COSTS OF LACED REINFORCED CONCRETE STRUCTURES

By

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ABSTRACT

Design procedures for determining the thickness of laced reinforced concrete elements subjected to the effects of close-in H.E. detonations are well documented in TM 5-1300. However, in some instances these procedures may be too time consuming particularly where only an estimate of the required thicknesses of protective structures is required. Therefore, a series of charts has been developed which will permit the concrete thicknesses of various laced structure configurations and quantities of explosives to be readily obtained. This paper describes the development of these charts as well as illustrating their use.

Analytical procedures are presently being developed which will enable the overall motions of cubicle-type structures to be evaluated. This paper describes these procedures as well as presenting a typical example of the design charts which will soon be available to determine the sliding and overturning motions of reinforced concrete cubicle-type structures.

In addition, this paper describes charts that can be utilized to obtain a reasonable evaluation of the construction costs of laced concrete structures and their components.

INTRODUCTION

Since June 1969 the design manual, "Structures to Resist the Effects of Accidental Explosions" (hereafter referred to as TM 5-1300), has been available to enable a quantitative evaluation of a structure's blast-resistant capabilities under the effects of a H.E. explosion to be performed. This manual documents the design procedures for protective structures constructed of laced reinforced concrete and subjected to close-in H.E. detonations. In some instances these design procedures can be too time consuming particularly if only an estimate of the concrete thicknesses and construction costs are desired. One such major situation is the need for the performance of concrete designs to establish budgetary cost estimates and safety approval in connection with the U.S. Army-wide plant modernization program of LAP and explosive manufacturing facilities.

Therefore, at the request of the U.S. Army Munitions Command (MUCOM), Picatinny Arsenal has undertaken a study, in connection with its overall explosive safety program entitled "Safety Engineering in Support of Ammunition Plants", to develop a series of preliminary design charts which greatly simplify the procedures for determining the thickness, configuration and construction cost of laced reinforced concrete structures.

This paper, which describes the development and use of the aforementioned charts, has been divided into three main sections, namely:

(1) Preliminary Design Charts for Flexure

(2) Design Charts for Structure Motions

(3) Estimated Cost of Construction

PRELIMINARY DESIGN CHARTS FOR FLEXURE

To obtain an estimate of the required concrete thicknesses of the laced elements utilized in forming a protective structure (hereafter referred to as a cell), a series of design charts has been developed. The concrete thicknesses determined from these charts should be considered only as preliminary and should not be used for final design unless all the parameters (such as explosive properties, structure configuration and strength) of an actual design situation exactly match the assumed parameters used in the design charts.

Development of Design Charts

In preparing the charts various explosive charge and structural parameters were considered. A discussion of these parameters is as follows:

Explosive Charge Parameters

The explosive was assumed to be spherical in shape and formed from bare TNT. For the design charts to be applicable to other mass-detonating materials and explosives whose shapes and casings differ from those considered in the chart development, the explosive energy of the "effective charge weight" of these other materials must be related to that of an equivalent weight of TNT. The establishment of the "TNT Equivalency" should consider the effects associated with close-in detonations as per TM 5-1300.

Depending on the method used to determine the TNT equivalent, either the effective or actual charge weight should be increased by 20 percent for design purposes. This factor of safety has been incorporated in the design charts and is a requirement of TM 5-1300. Therefore, when utilizing these charts, the value of "W" to be used is either the effective or actual charge weight.

The location of the explosive charge within a cell was based on three parameters which are illustrated in Figure 1 for various cell arrangements (or types). First, tha charge was positioned at the mid-length (L/2) of the element under consideration. If the explosive is located at points other than the mid-length of the element, the concrete thicknesses obtained from the design charts will be reasonably correct excaot for those cell elements which conform to panels supported on two adjoining edgas (Panel Type 2).

The second parameter for locating the explosive within a cell was tha clear separation distance of three feet between the explosive and one of the cell's elements adjoining the element under consideration. In most cases this parameter relates the position of the explosive relative to the floor slab of the cell. However, in some casas it is also used to position the explosive relative to cell elements other than the floor slab. In the latter cases, the charts needed for determining the element thicknesses are identical to those developed for similar panel types where the position of the explosive was related to the floor slab. For example, the design charts for the side and back walls of Cell Type No. 6 and the side wall of Cell Type No. 7 are identical to those charts used for the back wall of Cell Type No. 3.

The selected positioning of the explosive three faet abova the floor slab has been based on the usual positioning of explosives on conveyors, stands or within production equipment encountered in most explosive manufacturing facilities. For design situations where the explosive is positioned at an elevation higher than three feet, the concrete thicknesses given in the design charts will be consarvative. However, for elevations less than three feet, the

thicknesses given in the charts will be only slightly unconservative. The preliminary design charts are not applicable when the explosive is positioned in contact with the floor slab.

The third and last parameter considered in locating the explosive within a cell is the normal separation distance (R_A) between the center of the explosive and the cell element under consideration. Four values of the normal separation distance were included in the chart development, namely, a minimum value R_{MIN} and R_{MIN} plus 5, 10 or 15 feet. The values of R_{MIN} are based on the minimum clear separation distances recommended in TM 5-1300 and are illustrated in Figure 2.

Structural Parameters

In the development of the design charts, several structural parameters were involved. First, the panel types which define the individual laced elements utilized in forming the cell were considered. The panel type designation was based on the number of panel supports and the number of adjoining elements which will contribute to an amplification of the blast pressures acting on the element under consideration. For each of Panel Types 1 through 4, the number of panel supports and the number of pressure amplifying elements are equal. However, for Panel Type 5 the number of supports is one more than the number of amplifying elements. This situation occurs when the back wall of a structure separates an explosive operating cell from an adjoining non-explosive operating area such as a control center or shelter.

The second structural parameter involves the strength of the materials used to construct the cell elements. Concrete with an ultimate compressive strength equal to 4,000 lbs./sq. in. at 28 days was used. Reinforcement with

properties that conform to those specified by the American Society for Testing and Materials for deformed billet-steel bars ASTM A615 Grade 60 (yield strength equal to 60,000 lbs./sq. in.). The total percentage (vertical and horizontal) of flexural reinforcement assumed to be contained in each face of an element was one percent.

To maintain one percent flexural reinforcement in elements with a concrete thickness greater than three feet will require the use of bundled bars. Hence, the reason for terminating the design charts at a concrete thickness equal to 36 inches. The alternative to bundled bars would be to increase the element thickness and as a result reduce the percentage of flexural reinforcement to less than one percent to achiave the same blast-resistant capacity. Single layers of reinforcing bars are more economical than bundled bars.

The third and last structural parameter involved in the chart davelopment is the degree of structural response which an element is permitted to achieve. Design charts were prepared for a support rotation of two degrees, incipient failure and post-failure fragment velocity equal to 100 feet/second for Panel Types 1 through 4. In the case of Panel Type 5, charts were daveloped only for a dynamic response conforming to a support rotation of two degrees since personnel were assumed to be located within the control center or shelter which is composed of an element designated as Panel Type 5 (Cell Type No. 5). Rotations must be minimized to protect personnel.

Description and Use of Design Charts

a. Description of Charts

Each chart for the preliminary flexural design of a laced reinforced concrete element presents the variation of concrete thickness (T_c) with charge

weight (W) for a panel with various lengths (L) and a constant height (H). A typical design chart is illustrated in Figure 3. In addition to these parameters, each chart has been prepared for a specified panel type, normal separation distance (R_A) and degree of structural response. The variation that was considered for each of the latter parameters was discussed previously.

Four or more design charts have been grouped together depending on the number of panel heights (H) involved. A total of 52 groups of charts was prepared. In most cases heights of 8, 12, 16 and 20 feet were taken as illustrated in Figure 4. However, for elements designated as Panel Type 3 and having a structural response conforming to either incipient failure or post-failure fragment velocity, an additional panel height of 30 feet was considered to afford a wider range of structure dimensions for Cell Types No. 6 and 7 that could be covered by the design charts.

b. Use of Design Charts

A general procedure for using the preliminary design charts for laced reinforced concrete elements is as follows:

(1) Determine from Figure 1 for the structure under consideration the cell type which defines its overall arrangement. Also evaluate the panel types which define the individual laced elements of the structure.

(2) Determine the charge weight (spherical TNT equivalent) and as defined by the cell type the location of the charge including the parameter R_A and the panel length (L) and height (H).

(3) From Figure 2 evaluate the minimum separation distance (R_{MIN}) for the charge weight of Step 2.

(4) Select the design chart which corresponds to the desired structural response and the specified separation distance (R_A) and panel type.

(5) For the given panel length and height and charge weight, read the concrete thickness (T_c).

Interpolation may be required in many cases and should be accomplished by inspection for the panel length and by graphical means for the panel height and normal separation distance. An illustrative example using the design charts appears in the Appendix.

Required Thickness of Cell Floor Slabs

The concrete thicknesses presented in the design charts are only applicable for laced elements, and therefore, cannot be used to establish the design of cell floor slabs poured on grade. Based on past experience, a reasonable concrete thickness for the floor slab is equal to three-quarters the thickness of the thickest cell wall. The exception to the preceding recommendation is the floor slab of Cell Type No. 1 (cantilever wall). In this case the maximum thickness of the slab should be at least equal to that of the wall but may be reduced to a smaller thickness at the toe and heel. Layouts for multi-cell and cantilever wall structures are illustrated in Figures 5 and 6, respectively.

DESIGN CHARTS FOR STRUCTURE MOTIONS

Cubicle type structures subjected to the effects of close-in H.E. detonations will sustain the blast output of the explosion if the structure is designed to resist the flexural stresses produced by the blast pressures and the overall structure motions produced by the unbalanced loads acting on the adjoining sides of the cubicle walls. If adequate base support or support by adjoining walls is not provided, then the structure may be expected to slide and/or overturn. Therefore, a structure's configuration must be established to insure that its full flexural capacity is developed and overall motions are minimized.

The data presented in this portion of the paper will describe the design charts now being developed to enable the selection of correct properties of structures whereby overturning will be prevented.

Structure Motion Program

A computer program has been developed which will identify the overall motions of cubicle type structures when subjected to the effects of close-in detonations. Rotational and sliding motions are included and in the case of cantilever walls, the flexural response of the elements is taken into account. The results of the analysis of structure motions include the time-history of applied blast loads as well as the response of the structure to these loads. Also included in the analysis are the effects produced by soil-structure interaction.

The cubicle structure motions obtained from the above computer program have been compared and found to agree favorably with actual structure

motions observed in both full and model scale cubicle explosive tests (Reference 1).

The number of parameters involved in the analysis of structure motions is somewhat larger than that for the analysis of the flexural response of laced elements. In the case of the latter, the parameters involved are primarily those relating to the individual elements whereas the analysis for structure motions considers the structural properties of the entire structure and the soil properties. Here, the blast loads acting on the laced reinforced concrete walls, roof slab (if blast-resistant) and floor slab of the cell must be established. Also, the total mass of the structure must be evaluated which will require the establishment of the concrete thicknesses of the individual laced elements. Further, the properties of the soil must be determined by field testing.

A finite numerical integration procedure is used for performing the analysis of the structure motions. Except in those cases where the magnitude of the structure motions will be appreciably affected by the flexural response of the individual member, the overall structure has been assumed to be a rigid body. The soil-structure interaction has been accounted for by representing the soil below the structure by a series of springs which respond to the structure motions. Here, both elastic and inelastic properties of the soil were considered. Figure 7 illustrates typical actual and idealized stress-strain curves for soil.

Design Charts for Overturning

Based on the results of the above analysis, a series of charts

(Figure 8) is being developed which will define the concrete thicknesses and structure configurations required to prevent overturning. Each chart presents the variation of wall thickness (T_W) with charge weight (W) for a given structure arrangement whose cell dimensions are defined by length (L), width (b) and height (H) and with a base slab dimension defined by the width (B). In addition to the structure parameters, each chart is developed for a particular soil condition and charge weight location (R_A).

To describe how the variation in the above parameters will affect the configuration of a given structure, the following comparisons have been made:

1. <u>Variation of Cell Length (L)</u>

Figure 8 illustrates the variation of T_W as a function of L for both overturning of the overall structure and the flexural response of the individual elements. For small charge weights the concrete thicknesses for flexure will be larger than those required for overturning whereas for larger charge weights overturning requirements will govern. It should be noted that in this particular case the height of the wall (H) is equal to twice the width of the cell base slab (B) which is a severe condition insofar as overturning is concerned.

2. <u>Variation of Ratio b/B</u>

A variation in the ratio of the cell width to the base width of the entire structure from 0.45 to 0.7 (Figure 9) will not result in a significant increase in the required wall thickness to prevent overturning for the other parameters considered.

3. Variation of Soil Strength

A 30% increase in concrete thickness is required for a medium strength soil in comparison to that required for a high strength soil (Figure 10).

4. Variation of Soil Coefficient of Friction

The wall concrete thickness as a function of the coefficient of friction of a medium strength soil will vary with charge weight (Figure 11). However, for the parameters considered here, this variation will not be significant for charge weights as large as 500 pounds. For charge weights larger than 500 pounds the above variation will become more significant.

Design Charts for Other Structure Motions

It is contemplated that design charts will be available for determining structure motion effects in addition to sliding and overturning. These charts will include accelerations, velocities as well as vertical and horizontal movements of the structure.

ESTIMATED COST OF CONSTRUCTION

Once the thicknesses of the laced reinforced concrete elements have been determined, their total unit cost of construction can be evaluated from a series of cost charts that has been developed. In addition, charts for the costs and quantities of the individual components of laced elements have been prepared. This latter data will enable material and labor unit costs that differ from those selected as the basis of the cost charts to be used. The costs incurred due to contractor's profit, overhead and contingencies and design and administrative costs were not included in the total unit cost charts described herein. To determine the "in-place" cost of construction appropriate factors to account for these additional costs have to be developed for a given construction site.

Although the cost data has been developed primarily for incipient failure response of a laced element, its application to a response of either post-failure fragment velocity or support rotation of two degrees will not produce a significant error in cost effectiveness.

Total Estimated Construction Cost of Laced Elements

The total cost charts include material and labor costs for concrete, reinforcement and formwork. Each chart takes the form of total unit cost (per square foot of element surface area) versus concrete thickness for various panel lengths and a specific panel height.

Thirteen total cost charts have been prepared to cover the full range of panel heights and types. The charts for Panel Type 4 should also be utilized to determine the cost of elements designated as Panel Type 5. A typical total cost chart is illustrated in Figure 12.

Cost and Quantity of Laced Element Components

A series of charts to evaluate the material quantities and costs of the individual components of laced elements were developed. These components include concrete, flexural, lacing and diagonal reinforcement.

For flexural reinforcement one curve can be used to represent all panel types and response conditions because of the assumption employed in the development of the preliminary design charts, namely, the total percentage (horizontal and vertical) of flexural reinforcement contained in each face of an element is equal to one percent. The lacing reinforcement charts take the form of concrete thickness versus unit weight (pounds of steel per square foot of element surface area) and unit cost (dollars per square foot of element surface area) for a specific panel type and height and various panel lengths. Each chart for diagonal reinforcement is similar to those for lacing reinforcement except that the cell type and element identification (back or side wall or roof) instead of the panel type are necessary to define the quantity and cost of diagonal reinforcement. A typical component chart is illustrated in Figure 15.

Cost and Quantity of Floor Slab Components

Several charts to determine the material quantities and costs of the concrete and flexural reinforcement of cell floor slabs were developed. Each reinforcement chart takes the form of wall thickness versus unit weight (pounds of steel per square foot of floor surface area) and unit cost (dollars per square foot of floor surface area) for a specific cell type and wall identification (back or side wall) and various wall length to height ratios (L/H). The floor slab reinforcement perpendicular to the back and side walls of the cell must be evaluated separately and summed to obtain the total quantity and/or cost of the slab reinforcement.

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1. Levy, S. et al, Full and Model Scale Tests of Bay Structures, Picatinny Arsenal Technical Report 4168, February 1971.

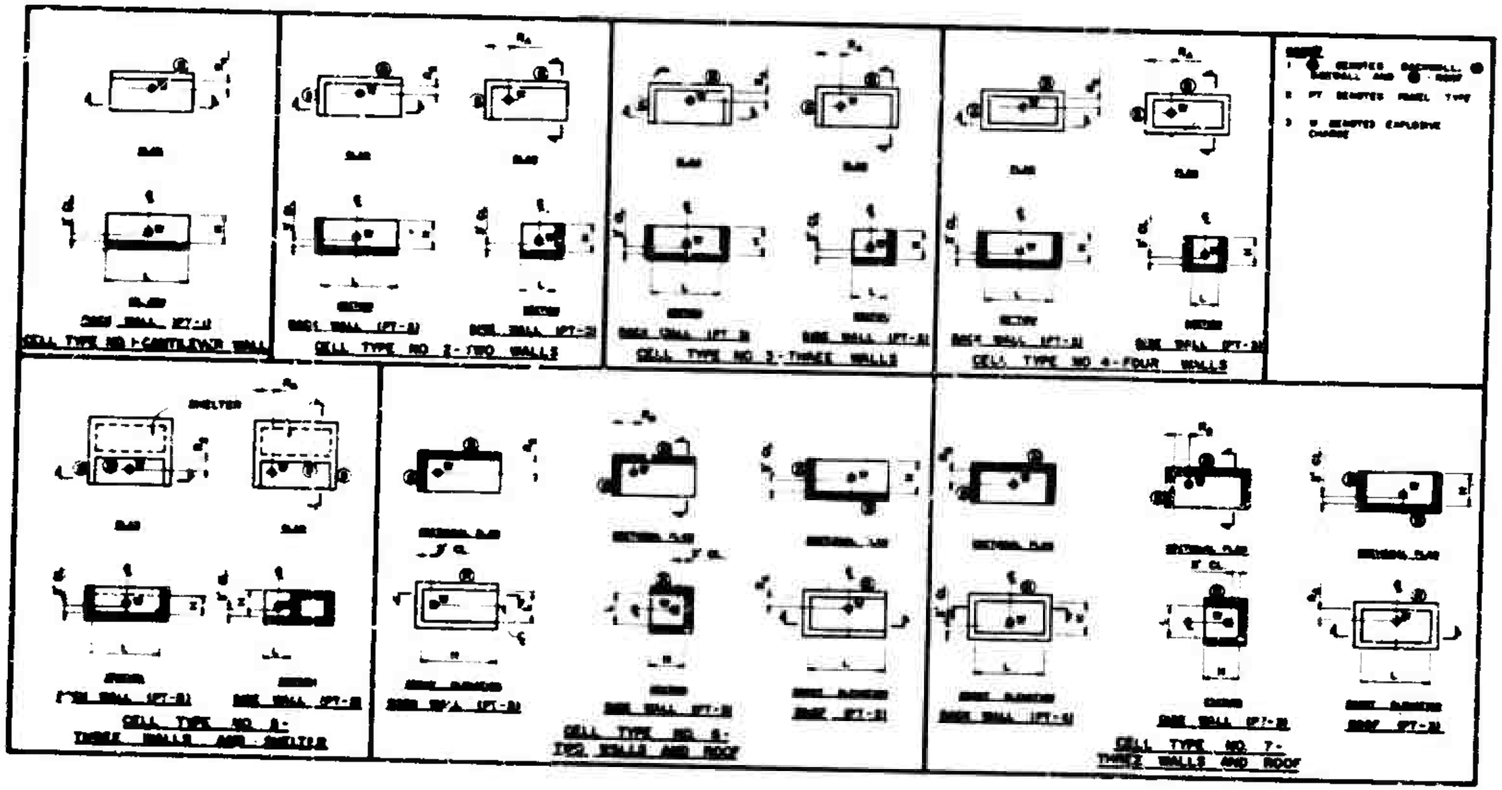


FIG.I CELL ARRANGEMENTS & PARAMETERS

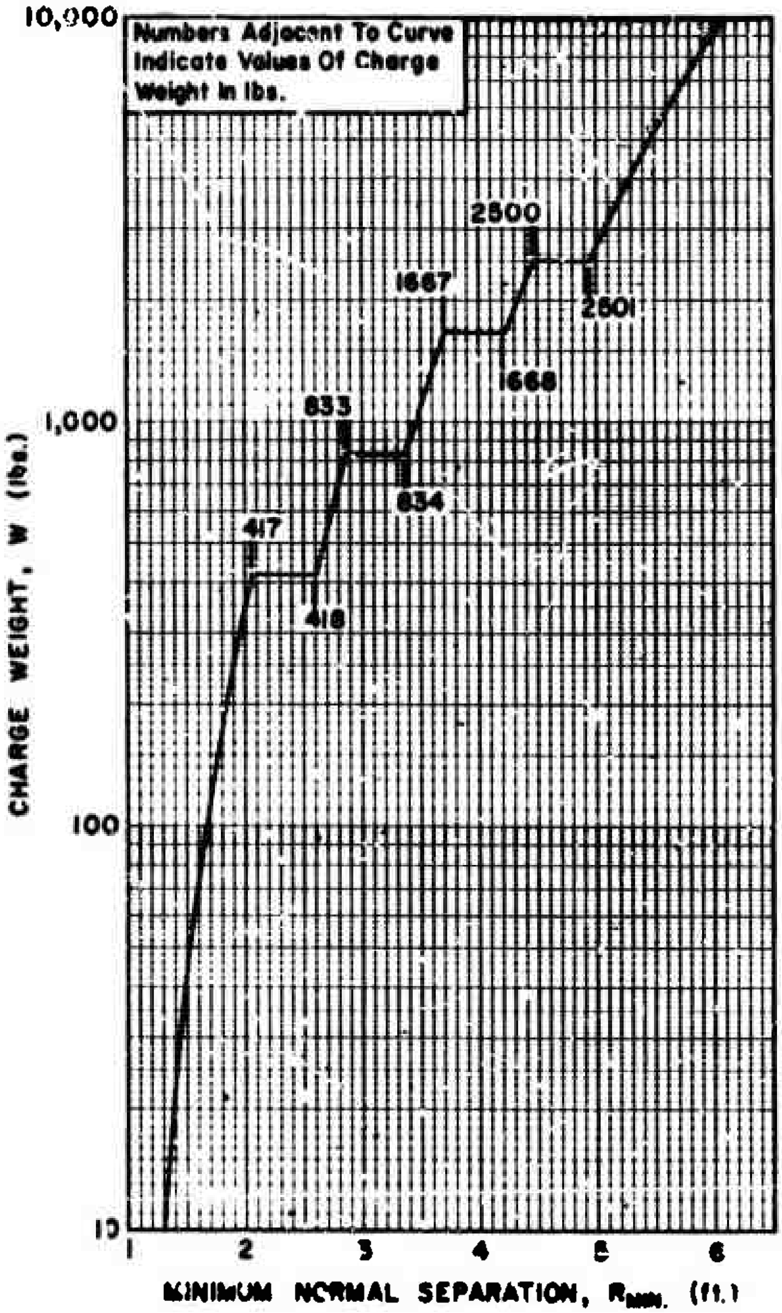


FIG. 2 MINIMUM NORMAL SEPARATION BETWEEN CHARGE & ELEMENT VERSUS CHARGE WEIGHT

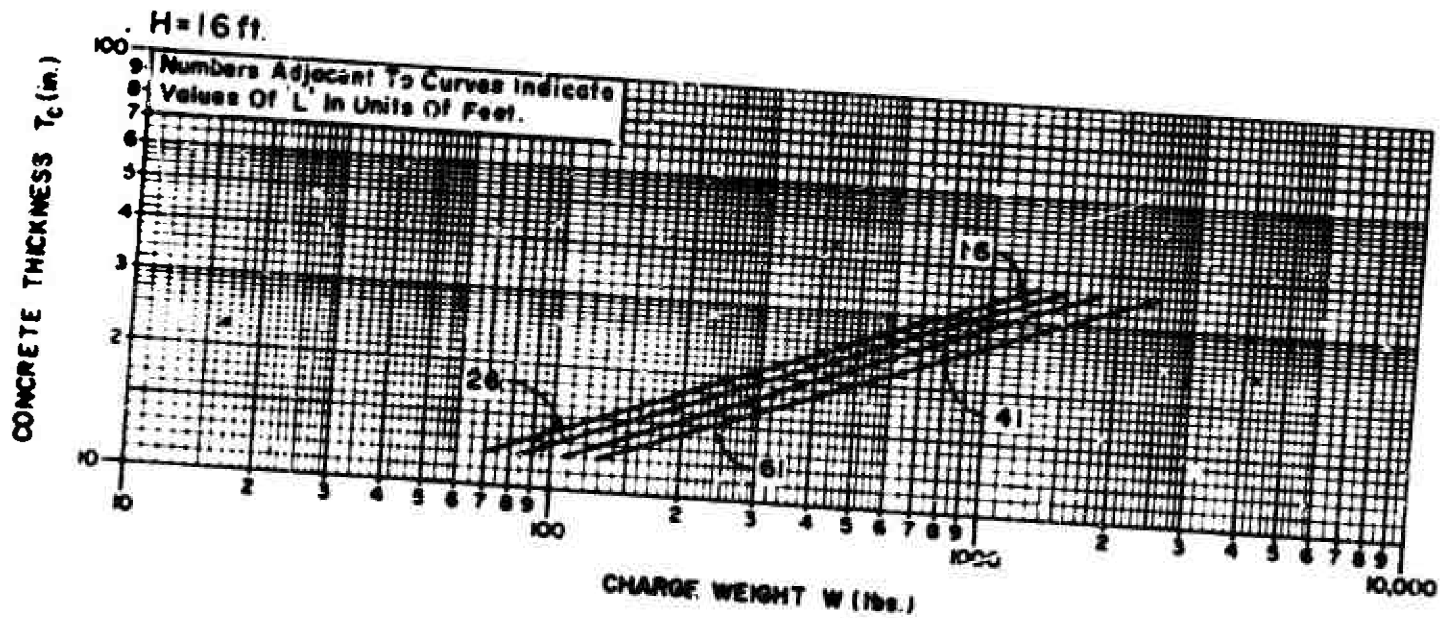
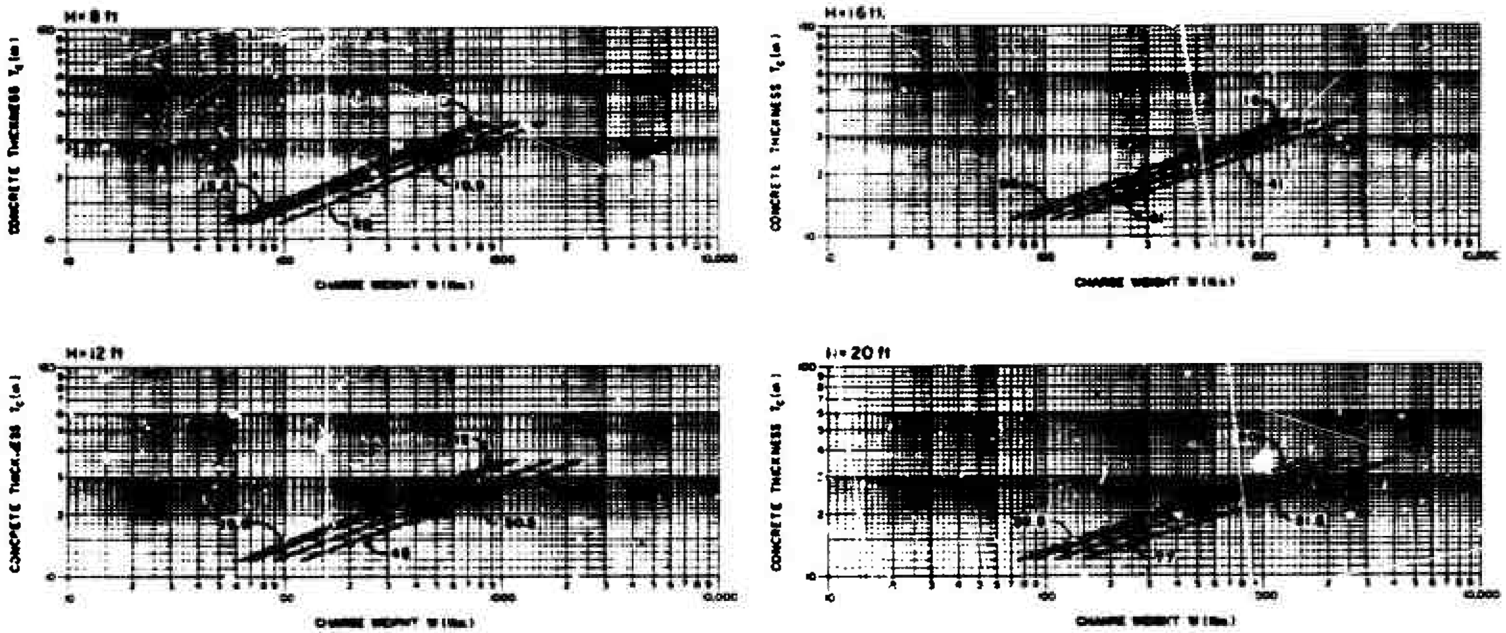
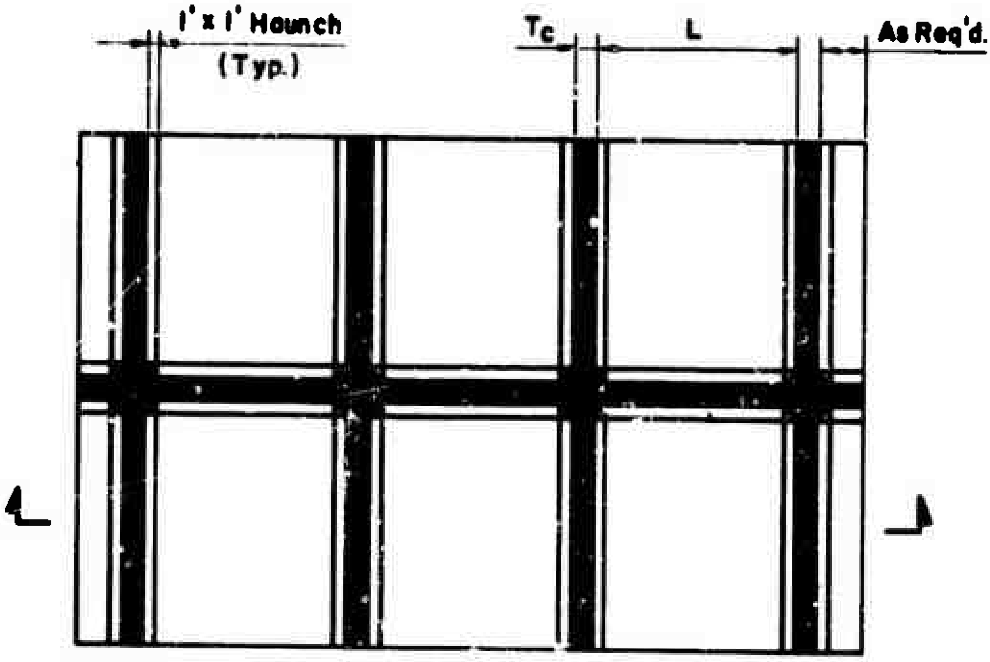


FIG. 3 DESIGN CHART FOR LACED CONCRETE ELEMENTS
(PANEL TYPE 2, $R_A = R_{MIN.} + 5'$, INCIPIENT FAILURE)

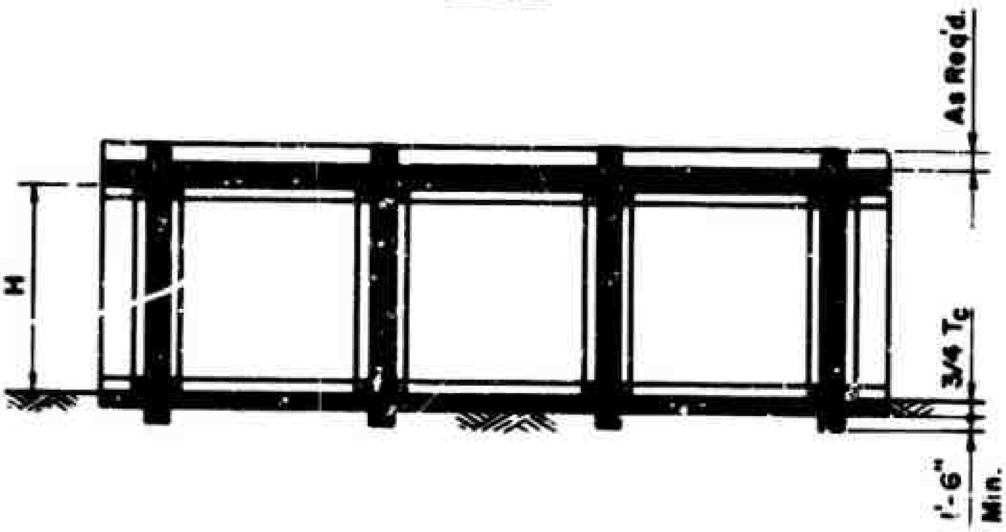


NUMBERS ADJACENT TO CURVES INDICATE VALUES OF "L" IN UNITS OF FEET

FIG.4 DESIGN CHARTS FOR LACED CONCRETE ELEMENTS
(PANEL TYPE 2, $R_A = R_{MIN.} + 5'$, INCIPIENT FAILURE)

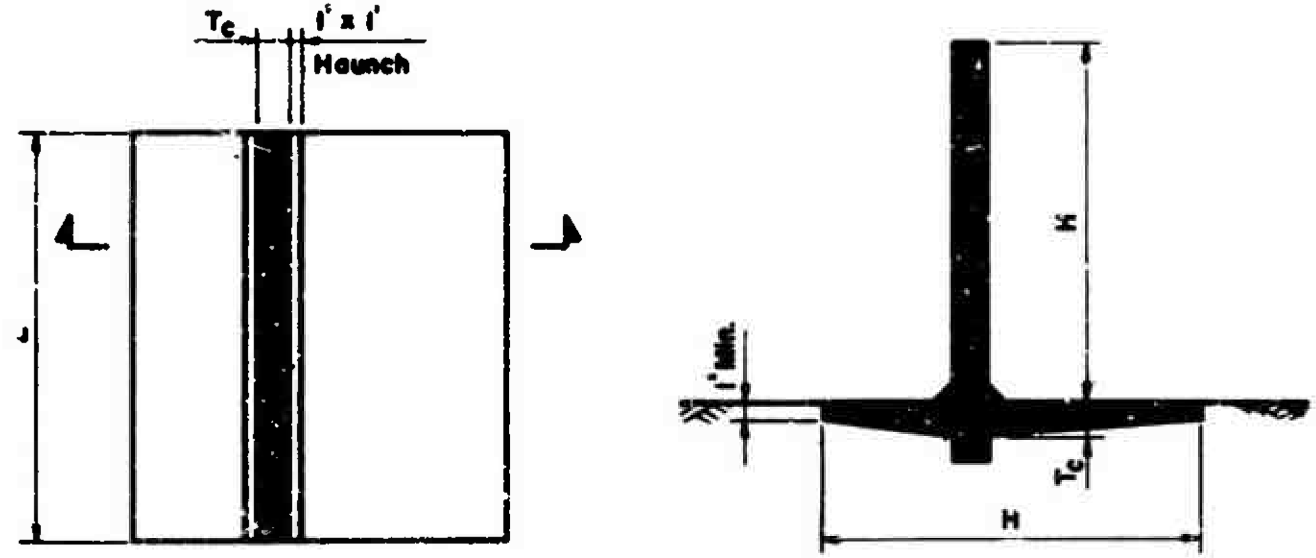


PLAN



SECTION

FIG. 5 MULTI - CELL LAYOUT



PLAN

SECTION

FIG. 6 SINGLE CANTILEVER WALL

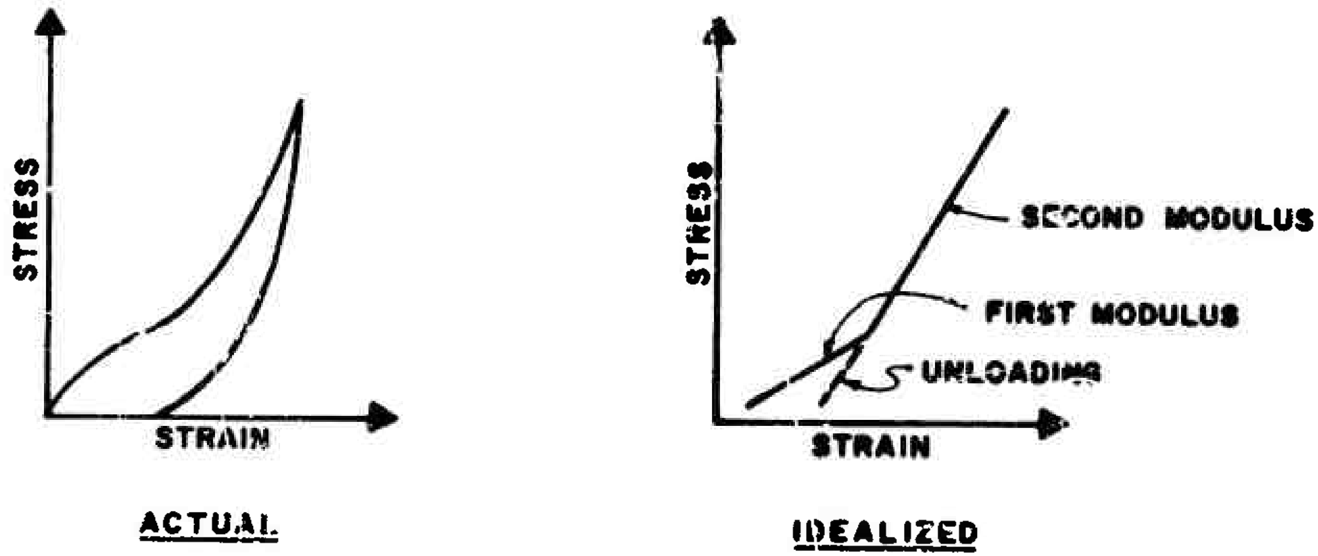


FIG. 7 SOIL STRESS - STRAIN CHARACTERISTICS

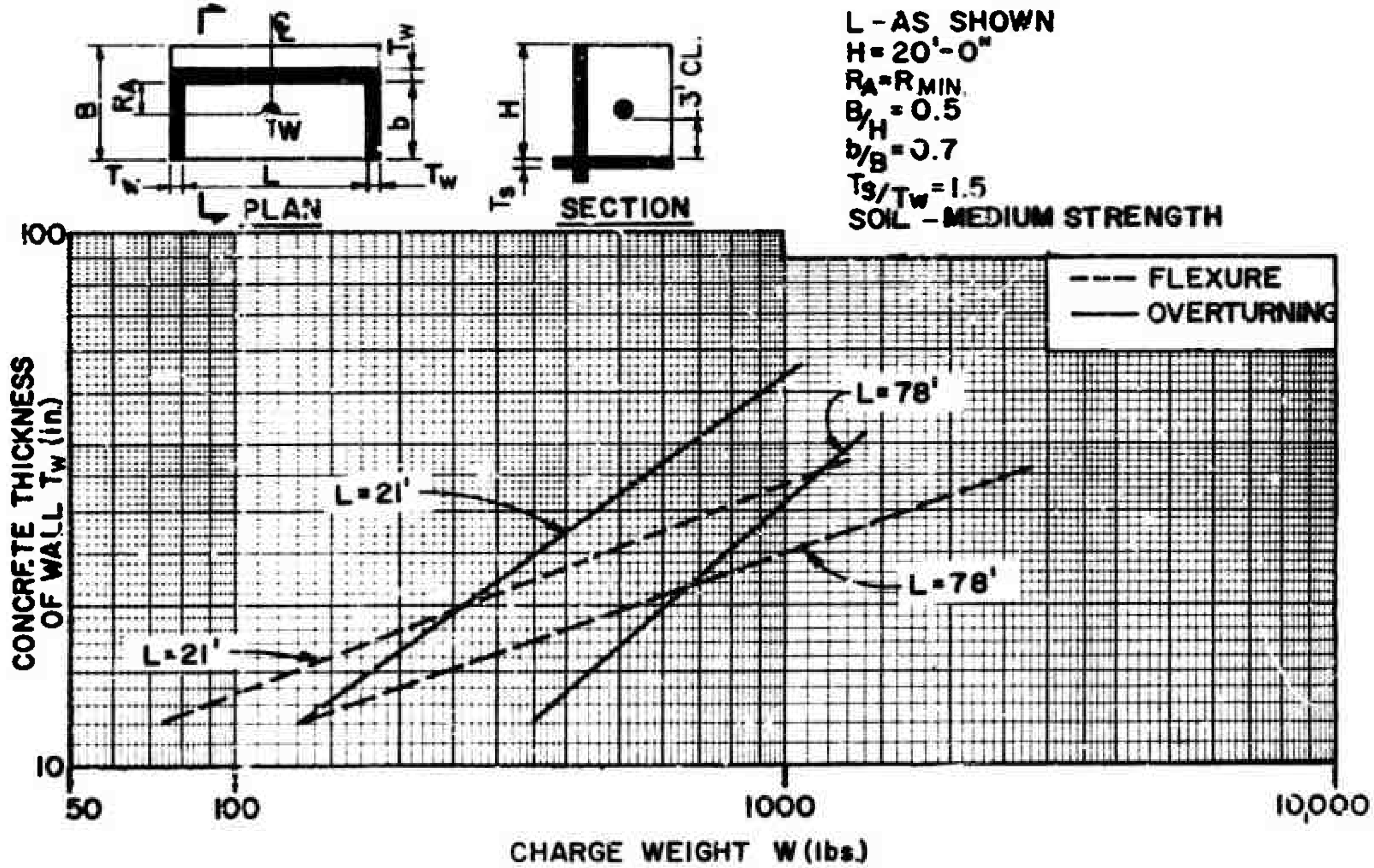


FIG. 8 TYPICAL OVERTURNING CHART FOR CUBICLE STRUCTURES

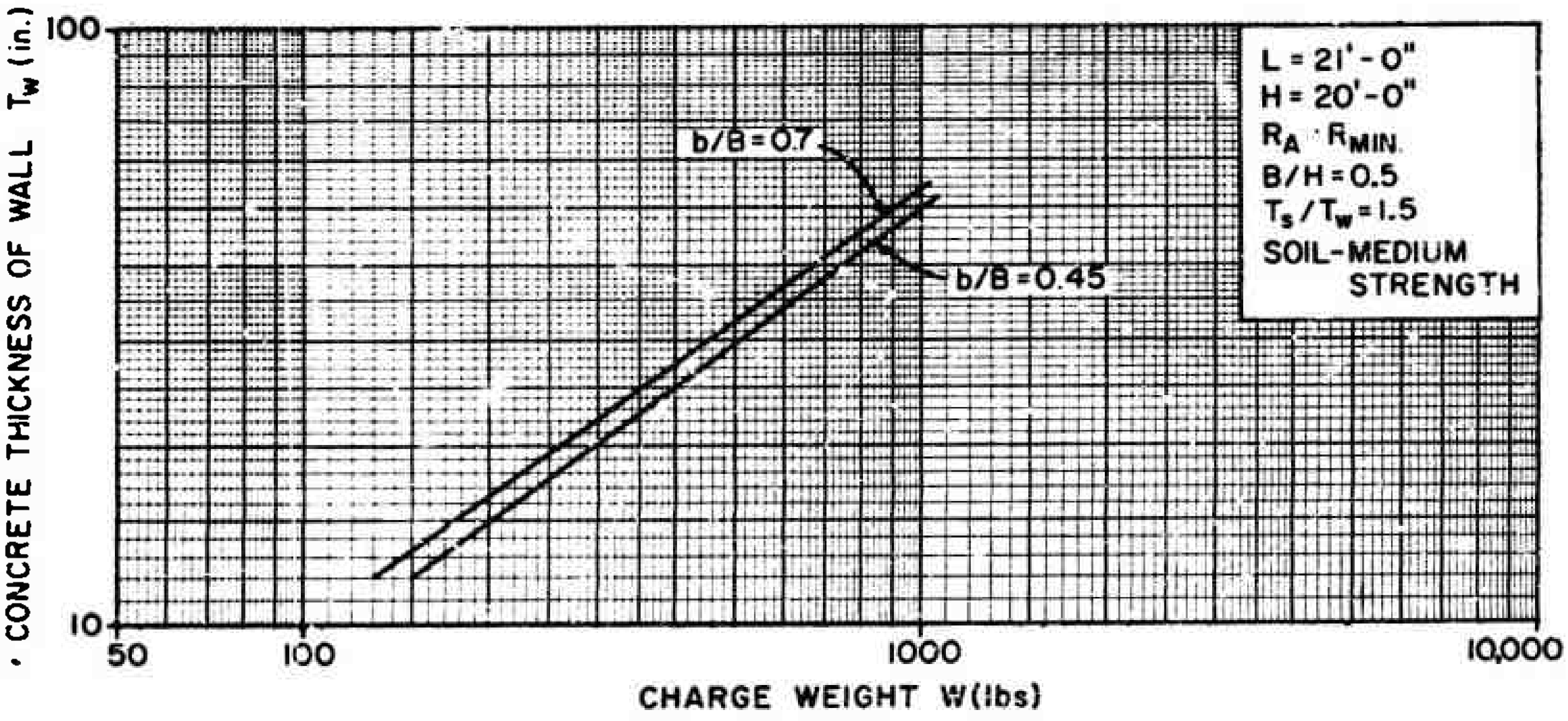


FIG. 9 VARIATION OF CONCRETE THICKNESS TO PREVENT OVERTURNING AS A FUNCTION OF RATIO b/B

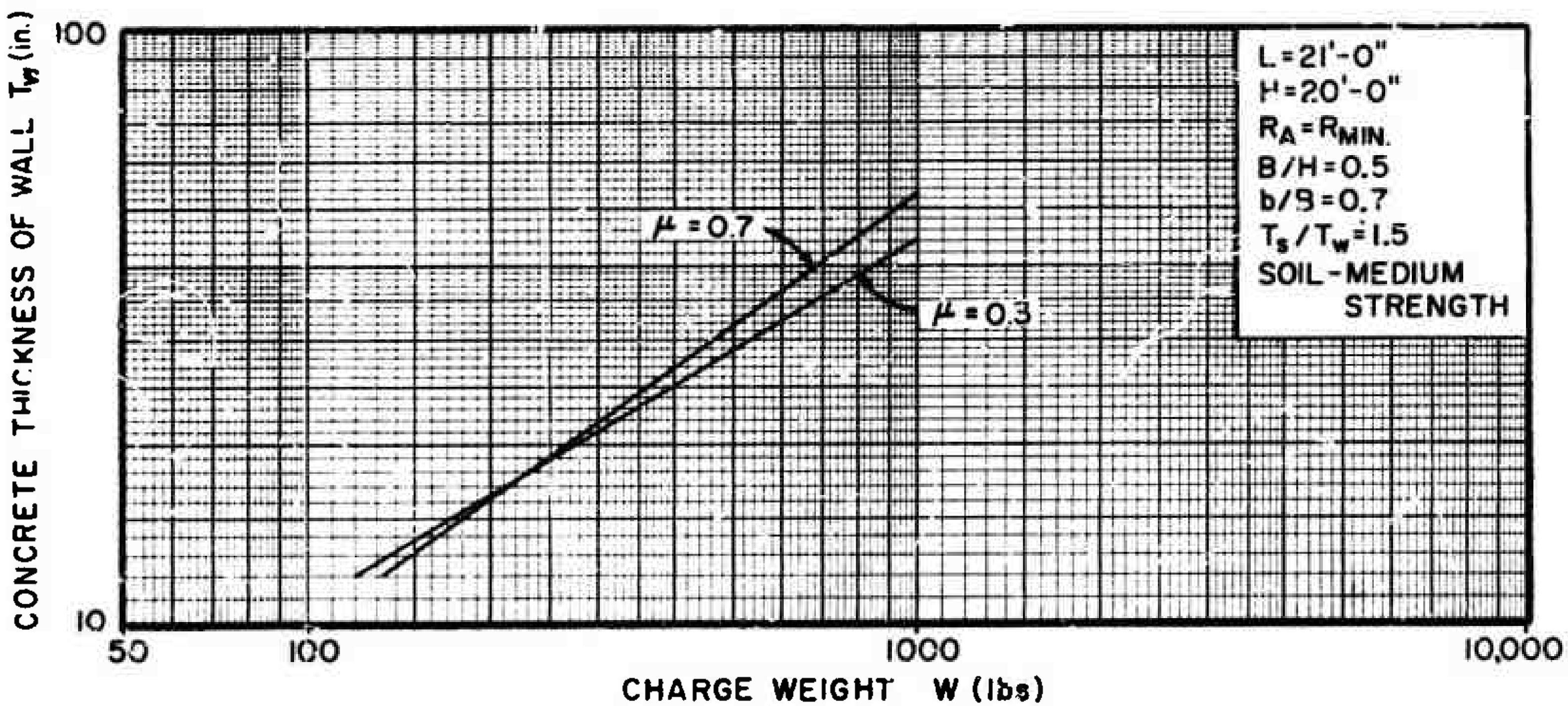


FIG.10 VARIATION OF CONCRETE THICKNESS TO PREVENT OVERTURNING AS A FUNCTION OF SOIL COEFFICIENT OF FRICTION

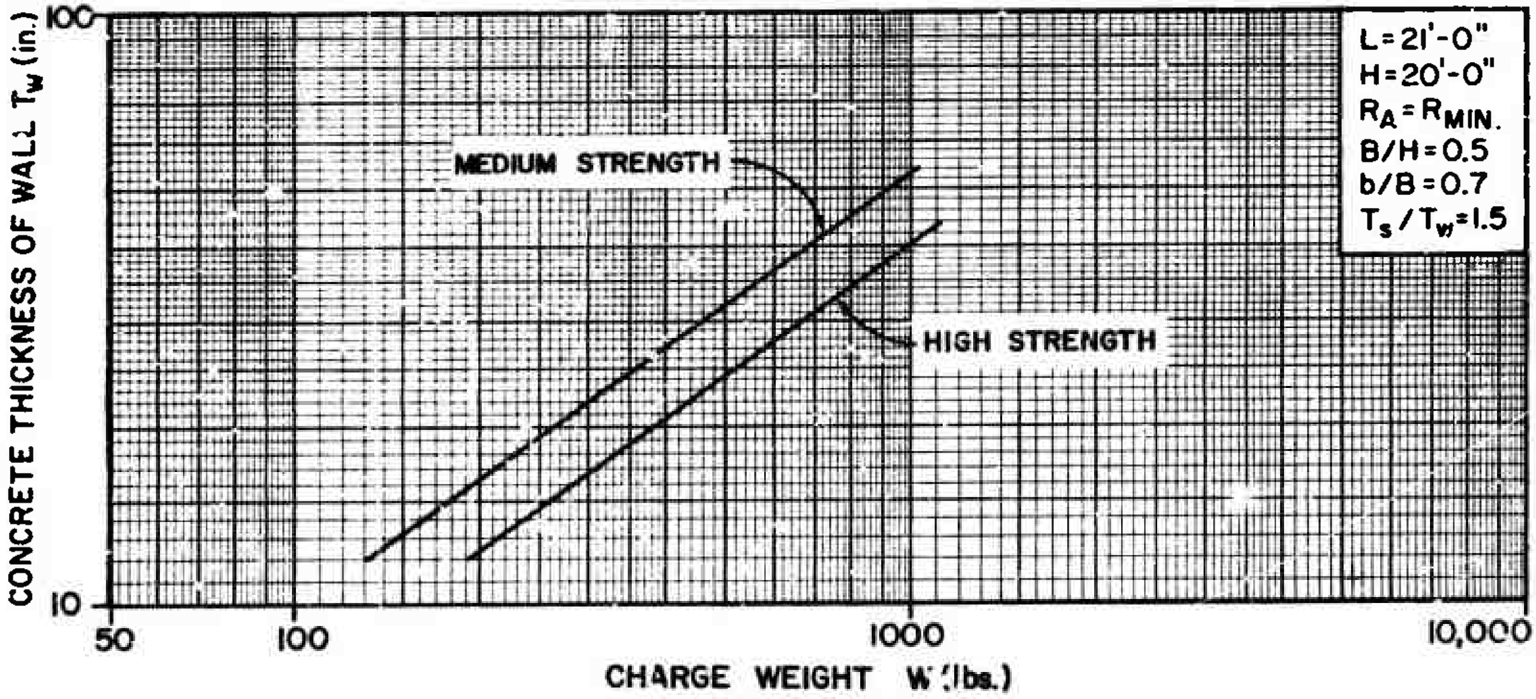


FIG. 11 VARIATION OF CONCRETE THICKNESS TO PREVENT OVERTURNING AS A FUNCTION OF SOIL STRENGTH

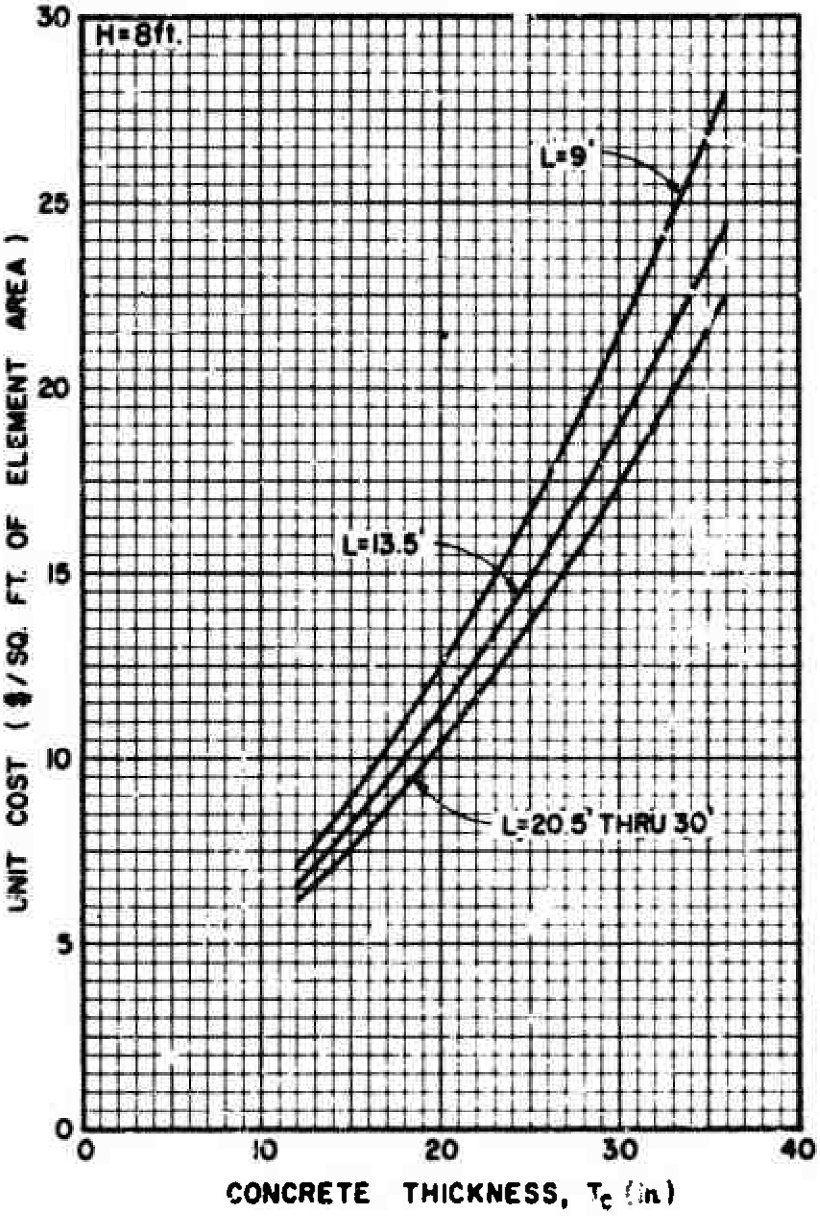


FIG. 12 TOTAL ESTIMATED UNIT COST OF CONSTRUCTION FOR LACED ELEMENTS (PANEL TYPE 3 - H = 8 ft.)

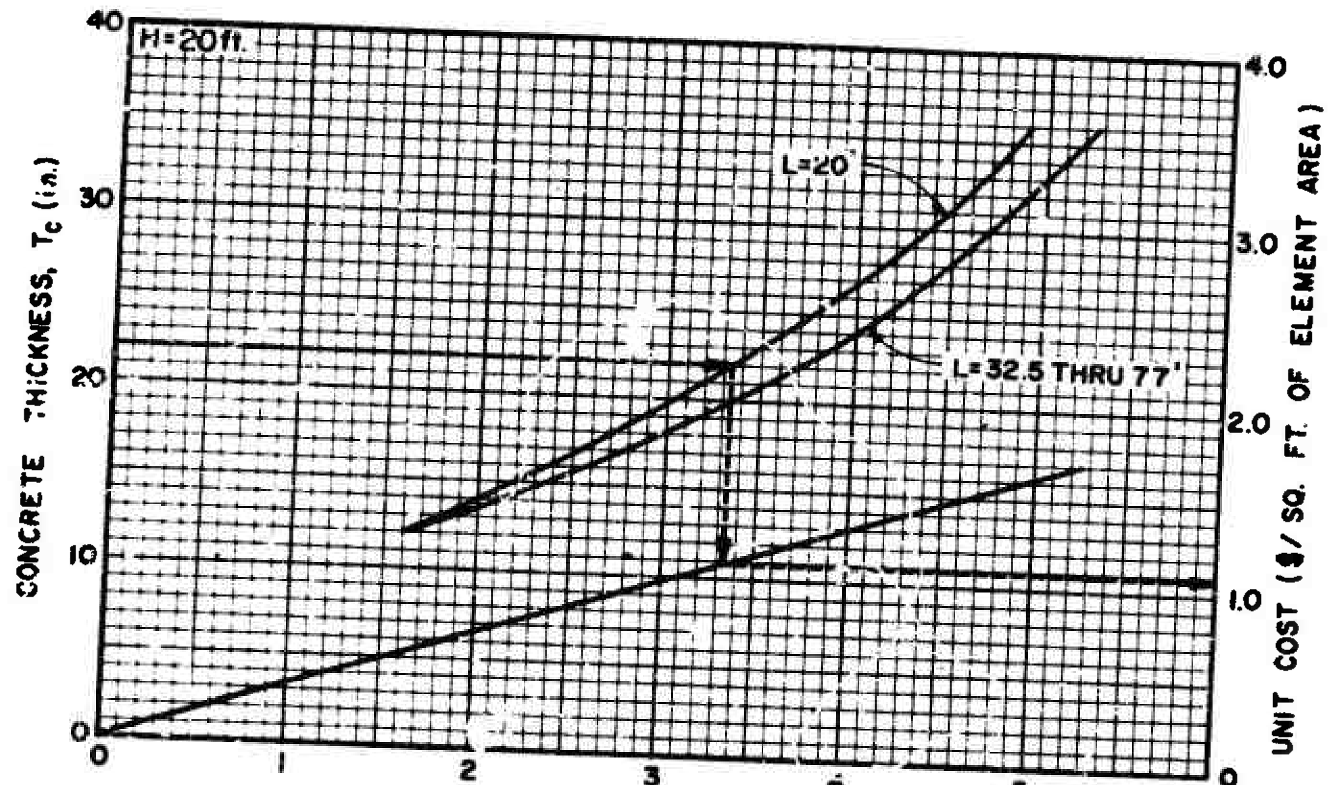


FIG. 13 UNIT COST & WEIGHT OF LACING REINFORCEMENT
(PANEL TYPE 2-H=20ft.)

APPENDIX

A. Example for Estimating Concrete Thickness of a Laced Element

Required: Determine the concrete thickness of the side wall of the cubicle shown in Figure 14. The wall is to resist the blast output of a spherical TNT charge weighing 1000 lbs. and is to be designed for incipient failure conditions.

Solution:

Step 1. Element is defined as a side wall (Panel Type 2) of Cell Type No. 3 (Three Walls) as shown in Figure 1.

Step 2. $L = 20$ ft. $W = 1000$ lbs.

$H = 13$ ft. $R_A = 8.5$ ft.

Step 3. From Figure 2 for $W = 1000$ lbs.

$R_{MIN} = 3.45$ ft.

Step 4. For the values of R_A and R_{MIN} stated above, the design chart for $R_A = R_{MIN} + 5'$ should be used. In this case interpolation for the panel height and length may be accomplished by inspection.

From Figure 4, concrete thickness $T_c = 34" = 2'-10"$

B. Example for Estimating Construction Cost of a Laced Element

Required: Determine the total cost of construction of the side wall of the cubicle shown in Figure 14.

Solution:

Step 1. Element is a side wall (Panel Type 2)

$L = 20$ ft. $H = 13$ ft.

Step 2. From Figure 15 for T_c = 34" (interpolation by inspection)

Total unit cost = \$18.50/sq.ft. wall surface area

Step 3. The total surface area to which the above unit cost should be applied is defined by L' and H' as indicated in Figure 14.

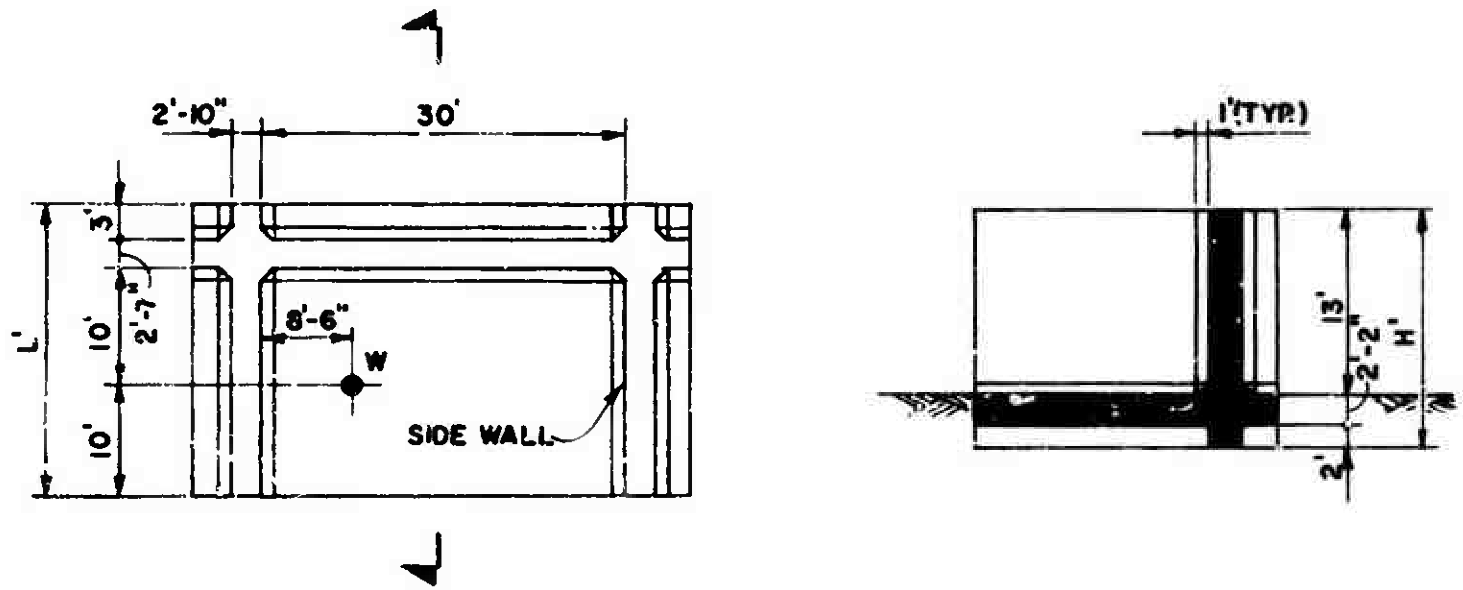
L' = 20' + 2'-7" + 3' = 25'-7"

H' = 13' + 2'-2" + 2' = 17'-2"

Step 4. Total cost of wall:

(18.50)(25.583)(17.167) = \$8125

Note: The above cost does not include costs incurred due to contractor's profit, overhead and contingencies and design and administrative costs.



PLAN

SECTION

FIG. 14

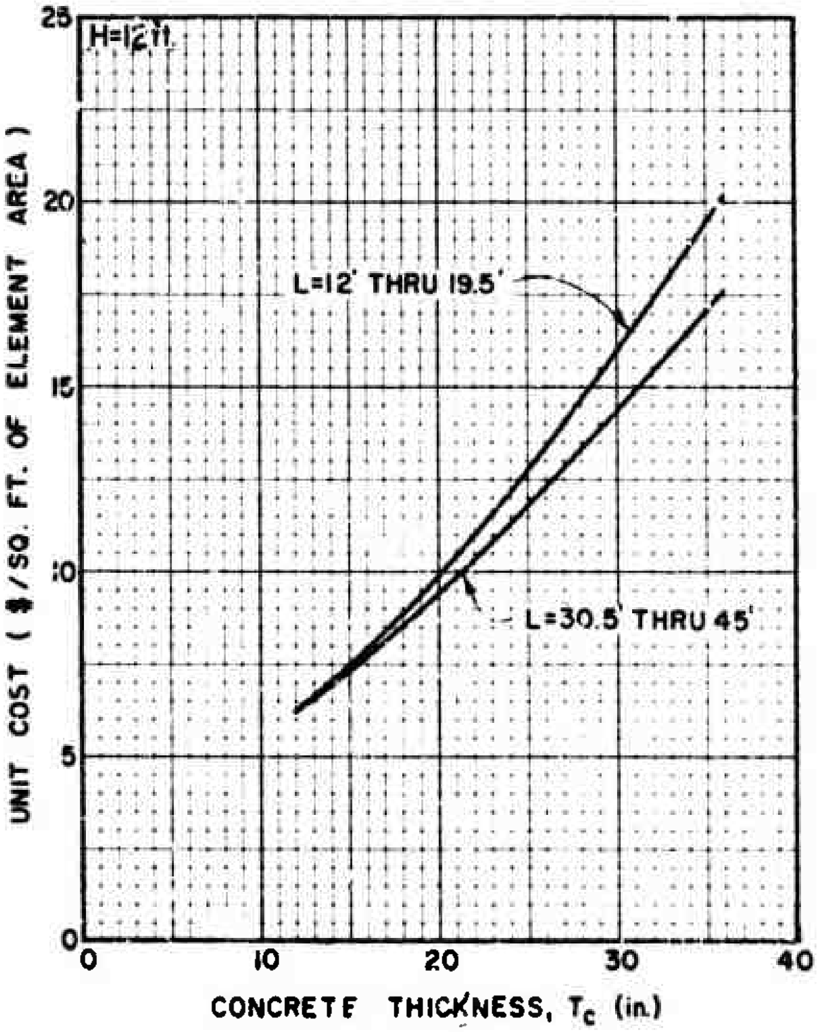


FIG.15 TOTAL ESTIMATED UNIT COST OF CONSTRUCTION FOR LACED ELEMENTS (PANEL TYPE 2-H=12 ft.)

EXPLOSION HAZARD OF FUEL TANK ULLAGE WHEN IMPACTED BY INCENDIARY PROJECTILES

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INTRODUCTION

BACKGROUND

The caliber of the enemy threat to Army aircraft in close air support of front-line combat troops has been increasing. During the initial stages of the RVN conflict, the 7.62mm ballistic projectile was the primary threat. Recently, however, Army aircraft have been exposed to 23mm high-explosive incendiary (HEI) projectiles. Thus, Army aircraft now in the design stage must meet the requirement of maximum survivability against the mid-intensity conflict threats.

The fuel system is one of the most sensitive systems to combat damage. First it occupies a large percentage volume of the aircraft, so it presents a comparatively large target. Secondly, if it sustains a hit, the probability of leaking fuel, in-flight fire, or catastrophic explosion is high. Therefore, one of the areas of study to increase the survivability of Army aircraft is the fuel system.

Developing design criteria for overall fuel system survivability encompasses a very large technical area. Obviously, the system should not leak, burn, or explode when impacted with enemy ordnance. However, when one considers the many types of enemy projectiles, the multitude of possible hit locations and attack directions, and fuel system design parameters, the task of formulating valid design criteria for increased survivability is a formidable one. This particular test program is an investigation of one type of ballistically-induced failure mode - that of an incendiary projectile passing

horizontally through the ullage of a fuel tank, igniting the fuel vapor, and causing a catastrophic explosive overpressure. The problem is being addressed in a three-phase program, the first two of which have been completed. Phase I involved a detailed investigation of the fuel cell ullage to quantify the explosive potential in terms of fuel/air ratio as a function of flight parameters. Under Phase II, incendiary projectiles were fired into known fuel/air mixtures to establish the ignition limits and characteristics under combat conditions. Work now in progress under Phase III is aimed at developing systems and design criteria based on experimental data that will eliminate the possibility of ullage explosions.

PREVIOUS TEST PROGRAMS

Phase I and a portion of Phase II are completed and have been reported. However, they will be discussed briefly to provide a background for the test program described herein.

The initial investigation involved the measurement of fuel/air ratios in the ullage of a fuel tank under simulated flight conditions. A typical test was conducted as follows. The test tank was filled with fuel in compliance with the test parameters. Flight conditions were then simulated by withdrawing the fuel, regulating the pressure, and vibrating the tank as the ullage was monitored. A matrix of test conditions was studied so that an ullage fuel/air ratio map could be predicted for typical Army mission profiles. In general, it was found that a fuel/air vapor gradient tended to be formed as shown in Figure 1. As expected, the mixture tended

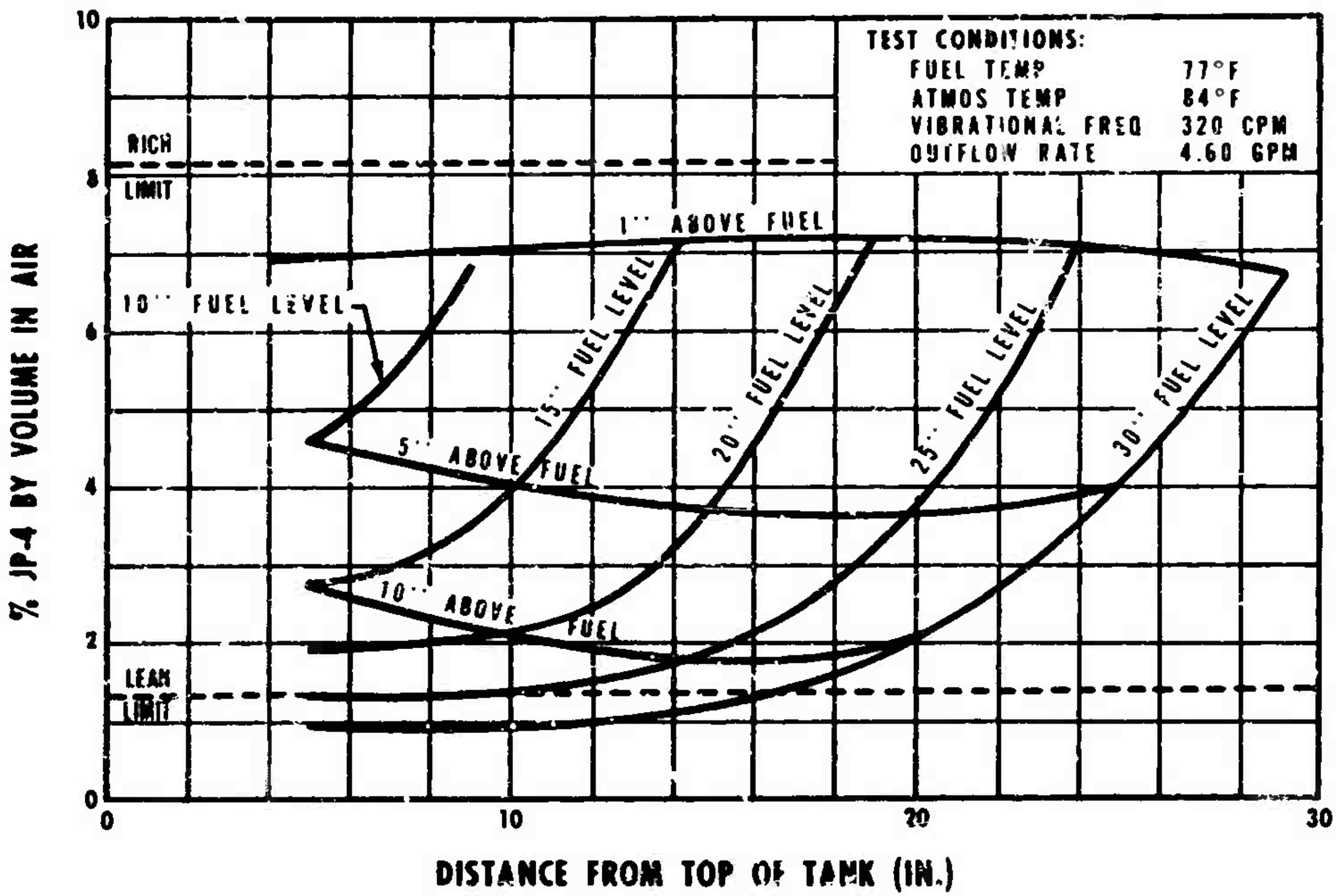


Figure 1. TYPICAL RESULTS OF TESTS IN WHICH ULLAGE VAPORS WERE SAMPLED UNDER SIMULATED FLIGHT CONDITIONS.

to be rich near the fuel surface and lean near the tank vent. More important this range of mixtures was such that it rendered some portion of the ullage hazardous (within normally accepted flammability limits) for almost all flight conditions.

Having determined that flammable mixtures do exist in the ullage, the next step was to determine their ignitability when subjected to an incendiary projectile. The composition used in the projectile is deficient in oxygen so that it uses oxygen from the ullage as it passes through. In addition, it produces turbulent mixing at entrance and exit. These factors indicate that ignition limits using an incendiary projectile are different from classical spark ignition limits. Therefore, a program was initiated to experimentally establish the incendiary limits. Several 1-foot-diameter Plexiglas cylinders of various lengths were modified so that they could be filled with a uniform fuel/air vapor mixture. Functioning .30 caliber incendiary projectiles were then fired along the centerline of the tube, and the reaction was observed with high-speed motion pictures. It was possible to vary the fuel/air ratio, tube length, and projectile velocity. The resulting ignition limits were established, and the possible independent effects of projectile velocity and tube length were examined. The ignition limits were found to be between 0.5% and 3.0% JP-4 by volume and were independent of the projectile residence times studied.

STATEMENT OF THE PROBLEM

The fact that the incendiary ignition limits were narrower than the classical

limits of 1.3 to 8.1% seemed to reduce the apperent axploeion hazard and eimplify the design of inerting concepts. However, these tests were conductad on uniform vapor mixturee. And since ullage usually conteins a ratber large fuel/air vapor gradient and the incendiary aource is very violent and widespread, it wes theorized that an impact in a nonflammable portion of the ullage might propegate enough energy to a flammabla portion to ignite it. Therefore, the experimental work described herein was conducted to examina the behavior of nonuniform vapor mixtures similar to those found in the ullage of aircraft fuel tanks when impectad with .30 caliber incendiary projectiles. It was hoped that ignition limits could be eetablishad and then appliad to the deta obtained in Phase I to obtain a more accurate explosion volume.

APPROACH

TEST PLAN

The ganeral plan was to generete a known, nonuniform vapor mixture and to impact it at a predetermined point with the incendiary projectile and record the reeults. The nonuniform mixture would generally contain fuel/air ratios from lean to rich as shown in Figure 1, and the incendiary impact point would ba chosen at or near the predictad limit in an attempt to isolate tha axplosion threshold.

TEST APPARATUS

The test tank, 23" x 27" x 30", was constructed of .250" aluminum. A 1-ft^2 hole was left in the top, as well as 6" x 6" antrance and exit holea for the projactile. Prior to each test, these holes were covered securaly with urethane rubber which would blow out during an explosion and relieve

the overpressure. The left and right sidee were made almoet entirely of Plexiglas tc allow photogrnphe to be taken of the tank interior during testing.

Heaters were located in the base of the tank, and an immersion cooler was available for fuel temperature regulation. The tank was mounted on a shaker table capable of providing e rocking vibretion to the tank up to 620 cpm. A load cell was fastened to one of the Plexiglas windows tc measure its response to the exploeion. Photogrephic coverage was provided at 400 and 1300 frames/second. A photograph of the test equipment is shown in Figure 2.

TEST PROCEDURE

First, the deaired vapor gradient was generated in the ullage by trial and error manipulations of the controlling parametera: the level of fuel in the tank, the fuel temperature, the mechanicel agitation, and the rete of fuel withdrawal. Sampling of the ullege was kept to e minimum to keep from aignificantly changing the test conditions. Large differencee in fuel temperature and ambient temperature were elso avoided to preulvde the poesibility of fuel or weter vapor condensation in or on the tank. Ultimately, all fuel was drained from the tank, leaving only the fuel vapors to burn. The ullage was sampled at 12", 18", 24", and 30" from the top of the tank immediately prior to testing.

All projectile impact conditions were identical. A 0.125" 2024-T3 aluminum sheet was placed 8 inchee in front of the tank and used to function the

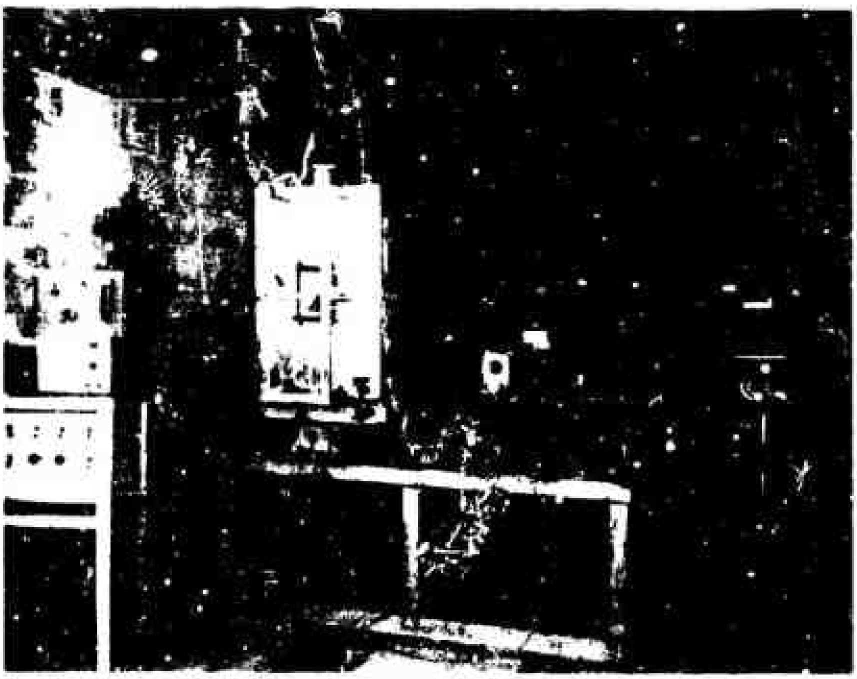


Figure 2. PHOTOGRAPH OF TEST TANK, HYDROCARBON ANALYZER, SHAKER TABLE AND HIGH SPEED CAMERA.

projectile. When the round was functioned in this manner, only the burning incendiary projectile passed through the tank and the ullage was not exposed to the initial intense function that occurred on impact. This test condition is most representative of a typical hit on an aircraft structure. A velocity of 2,000 ft/sec was used, and the impact point was 18" from the top of the tank.

The results were recorded with two high-speed cameras and a quartz load cell.

RESULTS

The primary information obtained from each test was simply whether or not an explosion had taken place, and this could be learned both from the load cell and the high-speed photographs. These data were used to establish lower and upper explosion limits and are plotted in Figures 3 and 4. The load cell also gave an indication of the explosive force on the sidewall as a function of time, and the photographic instrumentation recorded the physical characteristics of the incendiary function and ullage explosion.

Figures 3 and 4 indicate that explosions occurred when the fuel/air ratios at projectile impact were about 0.5% to 2.8% JP-4 by volume. These limits correspond closely to those found in the uniform vapor tests. Impacts at fuel/air ratios outside these limits failed to produce explosions even though a nearby portion of the tank was within these limits. Vapor sampling intervals were 6 inches apart, so in many tests in which one explosion occurred, flammable mixtures were no more than 6 inches from projectile impact.

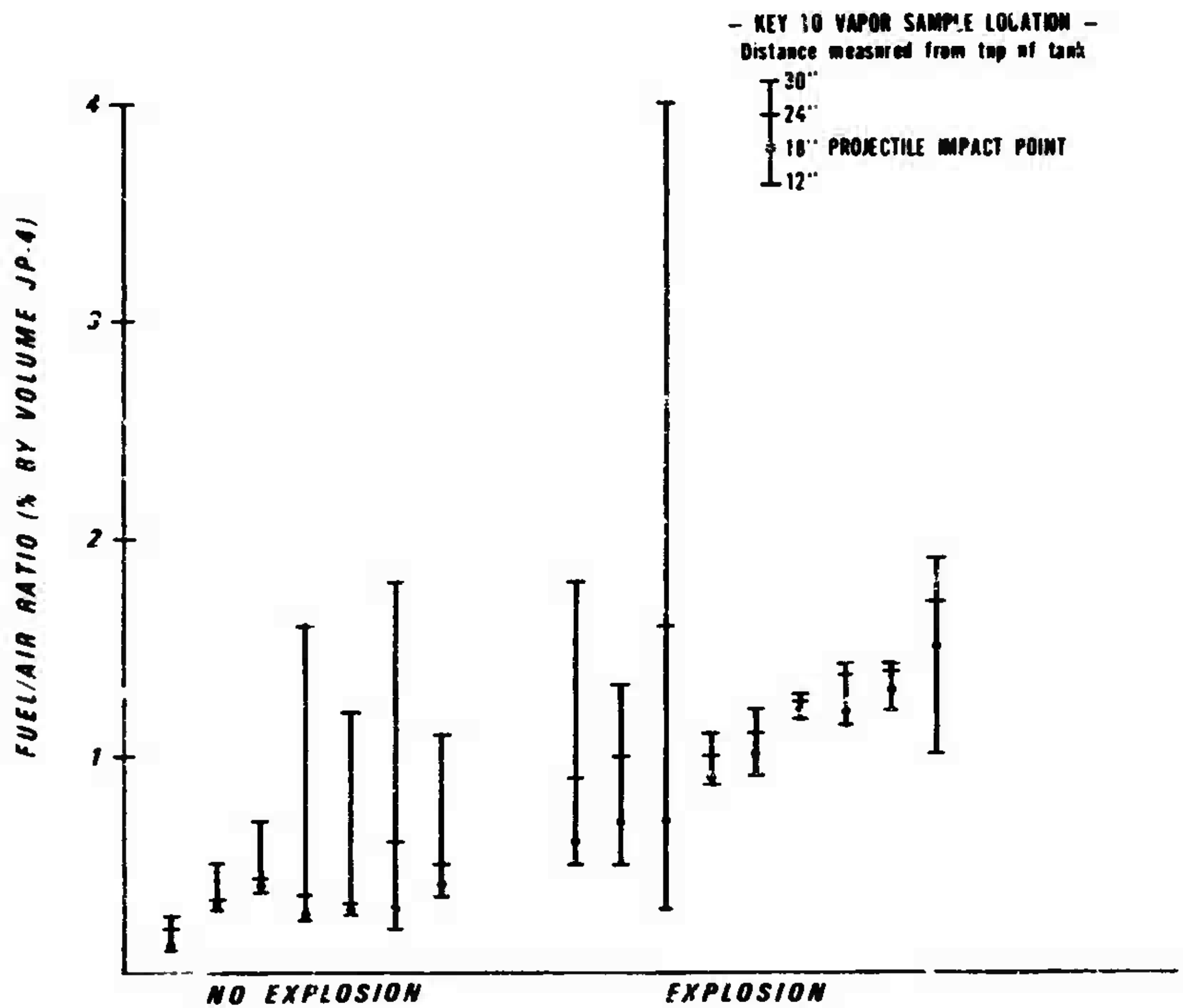


Figure 3. TESTS ESTABLISHING LOWER EXPLOSION THRESHOLD.

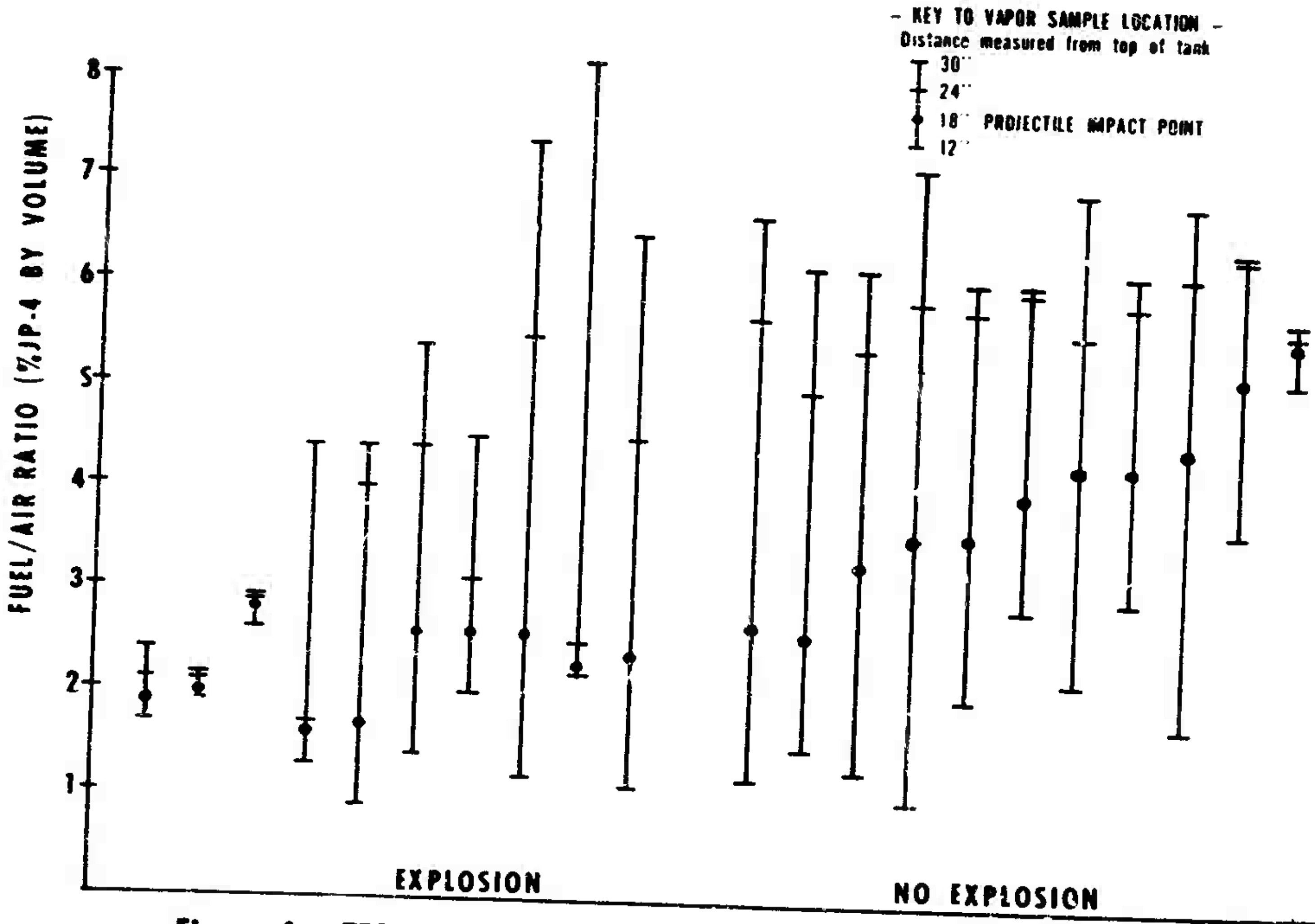


Figure 4. TESTS ESTABLISHING UPPER EXPLOSION THRESHOLD.

The explosions were relieved by blowout panels to preserve tank integrity; therefore, all load cell readings peaked at about the same value. However, a typical rise time of 20 msec/cm was recorded as shown in Figure 5.

The intensity of the explosion could be observed in the high-speed motion pictures. Once an ignition took place, the explosion progressed rapidly and seemed to consume all vapors in the ullage. No snuffing of the explosion by nonflammable mixtures was observed.

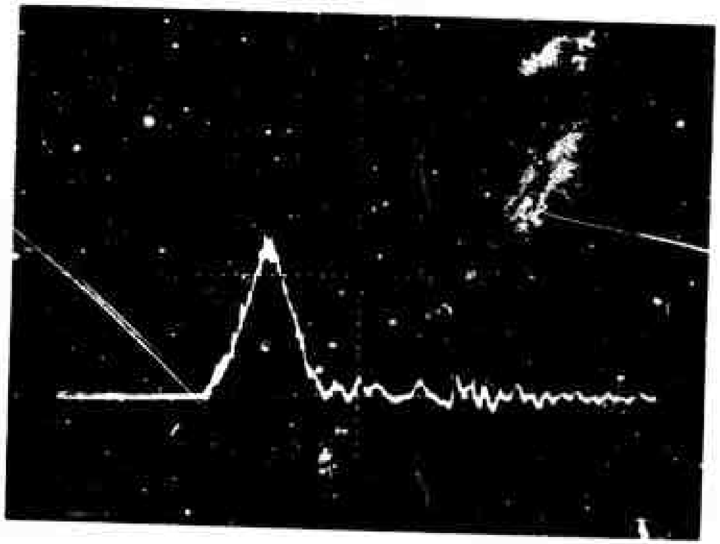
CONCLUSIONS

A .30 caliber incendiary projectile is capable of igniting fuel/air vapor mixtures found in Army aircraft.

Ignition of the ullage occurs when the fuel/air ratio at impact point is between 0.5% and 2.8% JP-4 by volume.

Inerting concepts that raise the fuel/air ratio in the ullage above the ignition limit are most promising since the upper ignition limit is low and JP-4 is highly volitile.

FORCE → 400 LB/CM



TIME → 20 MSEC/CM

Figure 5. TRACE TYPICAL OF LOAD CELL OUTPUT

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THE PROBABILITY OF TRANSPORTATION ACCIDENTS

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Many of us have often asked the question, "Which is safer -- truck or rail? Or water? Or air?" There are more answers than there are good answers. Rarely do the answers we hear explain the considerations leading to the stated conclusion. The answers are often based on emotion, depending on the personal accident experience of the respondent. It's like the case of small airplanes. If a man gets drunk, runs his car into a bridge, and kills himself, the obvious conclusion is that drunk drivers are dangerous. If that same man gets drunk, runs his Cessna 172 into a mountainside, and kills himself, then it's the airplane that's dangerous. Why the difference? Emotion. The statistics show very clearly that the accident rate of small airplanes is much lower than it is for automobiles, either on a per mile or a per hour basis. But those statistics are not what people feel - their emotions say that a car is safer.

In trying to answer the question of which mode of transportation is the safest, emotion, although sometimes more effective than statistics, does not provide a very good basis for a rational approach to the problem. If we want to evaluate the relative safety of a shipment of explosives, or radioactive materials, or other hazardous materials, we owe the public and ourselves something better than an emotional evaluation.

We live in a world of hazards. We are surrounded by threats to our health, our welfare, and our economy. Amongst the many hazards we face is the one involving the transportation of hazardous materials. One of the hazardous materials with which we must concern ourselves is radioactive material.

Public safety in the transportation of hazardous materials is the subject of increasing emphasis. An article in the May 1970 issue of the Reader's Digest stated, "Transportation of hazardous materials on our roads, railroads, and waterways is a major and growing problem. One of every ten trucks rolling toward you on the highway today carries explosives, flammables, or poison."(1)

Questions have arisen in numerous public hearings on nuclear reactor operations with regard to the adequacy of public safety in the transportation of radioactive materials to and from nuclear reactors. There are essentially no statistical data on which to predict the amount of damage to radioactive material packages in the various types of accidents. In the past 25 years,

there have been only about 250 accidents or incidents in transportation recorded[2] [3] in which radioactive materials were involved. None[4] of the accidents or incidents caused any death or injury of people as a result of the radioactive nature of the material. In only about 30 percent of those accidents was there any release of radioactive material from the package or potential for a radiation dose exceeding that in normal transport. During this same period, several million packages of radioactive materials have been transported in routine commerce; DOT estimates[4] that at present about 800,000 shipments of radioactive material move each year in the United States alone. By comparison, there are close to 30 billion shipments each year of other hazardous materials. Since there have been no deaths, injuries, or serious releases of radioactive materials in transportation accidents during the 25-year life of the nuclear industry, we decided to undertake a theoretical analysis of accident risks.

Shipments of radioactive materials are not readily distinguishable from shipments of other hazardous materials being transported in routine commerce. They look like ordinary shipments. They are usually handled and loaded in an ordinary manner, using ordinary freight handling equipment. They are transported on a worldwide basis, like other shipments, in the cargo compartment of an airplane, in a closed trailer or railroad boxcar, on "low boys" over highway, or on heavy-duty flatcars by rail.

We decided to look into the relative safety of different modes of transportation from a statistical basis, rather than an emotional one. However, even as we were collecting data and evaluating its applicability, we found that our own emotions came into play in judging which data would be useful and which data we should discard. In going through this study, we developed a methodology of simple data analysis that would lend itself to similar evaluations to questions such as "What's the likelihood that my shipment of explosives will be involved in an accident serious enough to cause it to blow up?" I would like to describe that methodology, and show its application to shipments of radioactive materials.

WHAT IS SHIPPED?

Nuclear power will play an increasingly important role in meeting the nation's energy requirements. As nuclear power increases, the quantities of radioactive materials which must be shipped will also increase. We used in our analysis the types of shipments made to and from nuclear power plants. These shipments, while only a small portion of the total number of shipments of radioactive materials, do represent the types of shipments about which the public seems the most concerned.

The operation of nuclear power reactors will usually require the transportation of three different types of materials to and from reactor facilities. Unirradiated ("cold" or "fresh") nuclear reactor fuel elements are transported from fuel fabricators to the reactor. Irradiated ("spent") fuel elements and radioactive waste are shipped from reactor facilities to fuel reprocessing plants and to storage or disposal sites.

About 95% of the 800,000 annual shipments of radioactive materials involve small quantities of radioactive isotopes for use in industry, medicine, agriculture, and education.(5) By comparison, the total number of shipments of radioactive materials to and from nuclear power plants in 1971 probably numbered only a few thousand.(6) By the year 2000, however, the numbers of shipments to and from nuclear power plants may increase by a factor of as much as 1,000.(7)

Other shipments of radioactive materials are made in support of nuclear power plant operations. For example, uranium concentrate, produced from uranium ore, is shipped from uranium milling plants in the western United States to uranium conversion facilities for conversion of the uranium concentrate to uranium hexafluoride. Uranium hexafluoride is shipped to one of the Atomic Energy Commission (AEC) uranium enrichment facilities. The enriched uranium hexafluoride is then shipped to other plants which convert the material to uranium oxide which is then fabricated into fresh reactor fuel elements. Also, the radioactive products of the spent fuel reprocessing plants consist primarily of recycled fuel materials shipped to fuel fabricators or processors and both high-level and low-level waste shipped to storage or disposal sites.

PRINCIPLES OF TRANSPORTATION SAFETY FOR RADIOACTIVE SHIPMENTS

Protection of the public and the transportation workers from radiation during the shipments of nuclear fuel and waste is achieved by a combination of limitations on both the contents (according to the quantities and types of radioactivity) and the package design. Shipments move in routine commerce, and on conventional transportation equipment. Shipments are, therefore, subject to normal transportation accident environments,(8) just like nonradioactive cargo. The shipper has essentially no control over the likelihood of an accident involving his shipment. He does have control over the consequences of accidents by controlling the package design, contents, and external radiation levels. Safety in transportation does not depend upon special handling or special routing.

In the transportation of all types of hazardous materials, there is a difference between potential hazards and realized damage. For hazardous materials, a system of protection is used to reduce the likelihood of the potential hazard from becoming a reality. A highly developed and sophisticated system of protection has evolved for the transportation of radioactive materials. This system is based upon a simple principle -- if a package contains enough radioactivity ("Type B" quantity) to present a significant risk of injury or large property loss if released, then the package ("Type B" package) must be designed to retain its contents during severe transportation accidents.[9] Lesser quantities ("Type A" quantities) do not require as much protection, but still must be packaged in high quality "Type A" packaging (like steel drums, cylinders, or strong boxes). In addition, all packages (Type A and B) are required to completely retain their contents during normal conditions of transportation.

The basic principles of safety are translated into the Federal Government regulations.

GOVERNMENT REGULATIONS

The transportation of radioactive materials is subject to the regulations of both the DOT[10] and the AEC.[11] The DOT Hazardous Materials Regulations also provide for safety in shipment of other more routinely shipped hazardous materials -- materials which are explosive, flammable, unstable, poisonous, or corrosive. The same basic safety standards governing shipments of radioactive materials in the United States are in world-wide use through the regulations of the International Atomic Energy Agency.[12]

In addition, the packages must provide adequate radiation shielding to limit the exposure of transportation workers and the general public. For spent fuel, the package must have heat dissipation characteristics to protect against overheating from radioactive decay heat. For both fresh and spent fuel, package design must also provide nuclear criticality safety under both normal transportation and severe accident conditions.

ACCIDENT RISK

Principle of Risk. The significance of environmental hazards during transportation of hazardous materials can be properly evaluated only by considering together the consequences of accidents and the probabilities of those accidents. One could compare the risks of transportation of hazardous materials in several ways. For example, one might compare the probabilities of shipment accidents;[13] one might compare the average cost of accidents by each mode of transportation; one might compare direct transportation costs, which include insurance premiums. However, all of these partial measures for comparing risk may be combined into a single contingency risk cost factor which is the product of the probability of experiencing an accident involving radioactive materials and the probable cost of such an accident if it occurs.

DIVERSION OF TRAFFIC FROM ONE MODE TO ANOTHER

The question of relative safety between different transportation modes becomes particularly significant when one considers some recent proposed changes in national transportation policy which would divert substantial volumes of traffic from one mode of transport to another. Each mode of transportation has its own distinctive accident, injury, and death rates. In judging which mode of transportation is the safest, we cannot limit our scope to just the considerations of the safety of our own freight. We must also look at the interrelated effects on the overall environment. In some ways, the accident rates are a reflection of the interaction between technology and environment for each mode. Pipelines are unmanned systems that operate in relative isolation from the general public. Commercial marine transportation uses large vessels that, with the exception of a limited interface with recreational boating and shoreside activities, do not impinge upon the general public. Railroads operate upon their own private right-of-way. Only in the highway milieu do we find freight transport intermixed with the general public.

The National Transportation Safety Board[28] has encouraged the movement of freight via the safest mode of transport. Because of the interrelationships of the accident data for the various modes, any change in national transportation policy which has the ultimate effect of transferring freight traffic from one mode of transportation to another may have significant safety implications.

The chart in Appendix A shows the projected[29] 1980 division of domestic surface freight ton-miles, both with and without the regulatory changes proposed in S. 2842, the Transportation Regulatory Modernization Act of 1971. This regulatory change would shift a substantial amount of freight traffic from trucks to the railroads. The implications of this shift from a less safe to a more safe mode of transport is a net savings for our society of approximately 550 deaths and 7,300 injuries avoided per year. If the railroads could attract one-fourth of the present long-haul truck traffic by deregulating freight rates,[31] the net safety benefit to our society flowing from this change in economic regulations could be 775 lives saved and 10,200 injuries avoided per year. (See Appendix B.)

On the other hand, the DOT is encouraging the nation's railroads to abandon some 21,000 miles of lightly used track (slightly more than 10% of the nation's trackage). Those lines generate less than 1% of the total rail ton-miles. It is estimated[28] that transferring 1% of the railroads' present ton-mileage to highways would result in approximately 60 additional deaths and about 800 additional injuries per year on our highways (to both truck drivers and others).

In order to more accurately assess the overall trade-offs in terms of what is best for public safety, the data used in the evaluations must in fact reflect not only parochial interests but also the side effects.

SELECTION OF DATA

In selecting the type of information we wanted to analyze, we decided to concentrate on those accidents which involved impact, fire, or both. We set up some arbitrary categories of accidents, ranging from minor to extremely severe, in order that we could examine any possible differences in accident rates for the different modes of transportation based on accident severity. We decided to eliminate air transportation from this study, only because the nuclear power reactor shipments do not go by air. The methodology we developed, however, would be just as applicable to inclusion of air shipment data.

In the case of highway shipments, we eliminated automobile accident data, because everything moves by truck. In the case of rail accident data, we eliminated grade-crossing accidents, because any involvement of rail cargo in such accidents is extremely rare. We made other such exceptions. We kept in the back of our minds that the types of packages we were concerned about were designed to withstand severe impact, puncture, and fire stresses. In order to understand our rationale behind the selection of the data we used, it would be useful to describe these package standards.

DESIGN PARAMETERS FOR RADIOACTIVE MATERIALS PACKAGES

DOT and AEC regulations specify certain package accident damage tests[14] which provide a means for reproducing in the laboratory or in the field the same general type and degree of damage certain packages might reasonably by expected to sustain in a severe transportation accident. Any package which can be shown to meet those standards is called a "Type B" package and can be expected to withstand severe accident conditions without significant leakage or shielding loss. The tests do not in themselves represent a specific transportation accident.

There are four such tests. They are a 30-foot freefall onto a flat unyielding surface, a 40-inch freefall onto a steel plunger, a thermal test and immersion in water. For purposes of establishing the relationship between the accident severity categories (described in Appendix A) and actual types and conditions of package damage, the 30-foot freefall and the thermal test will be discussed in some detail.

Various factors limit the effect accident conditions will have on a package.[15] For instance, the 30-foot freefall drop test is representative of the damage sustained in most real accidents in which the vehicle speed at the time of impact is greater than 50 mph.[16] Although the velocity at the point of impact in the drop test is about 30 mph, the test requires dropping the package on an unyielding surface. In a real accident, the forces the package sustains are mitigated by the angle of impact of the vehicle, the crushing of the vehicle which absorbs much of the impact and the fact that, for impacts of heavy objects such as transporting trucks, the object with which the truck collides in most cases yields and thus absorbs some of the impact.

For example, in an instrumented full-scale test of a 15-ton cask on a semi-trailer in which the trailer was driven into an immovable barrier at almost 30 miles per hour,(17) the cask received only a fraction of the stress it was designed to withstand. The cask remained tied in place on the trailer and was undamaged, while the tractor was completely demolished.

As part of that same test, a semi-trailer truck loaded with several different types of drums was driven into the immovable target at 42 mph. Several of the drums lost their lids but none of the inner containers was released or opened. About 50% of the drums were not damaged at all.

With respect to fire, the Type B package must be designed to withstand the thermal test in which the package is subjected to a temperature of 1475°F for 30 minutes. Recognizing that under actual fire conditions, the temperature rise is gradual, rather than a "step function," there is general agreement that it is highly unlikely that a transport fire lasting up to 1 hour would produce damage more severe than that resulting from the thermal test.(18)

Some accidents will produce stresses on packages equivalent to those produced by the accident damage test conditions specified in the regulations for Type B packages. Although sufficient data are not available to specify exactly which accidents are equivalent, the "severe" category is considered to be generally equivalent. Therefore, for the purposes of this paper, it has been assumed that Type B packages are designed to withstand accidents in the severe category (described later) without significant loss of contents or shielding.

The regulations offer a very high degree of assurance that a package will not breach under severe accident conditions.(19) A specific safety analysis report must be prepared for each package type and evaluated by the AEC before use.(20) Only after the packaging has successfully passed such rigorous evaluations will the DOT authorize its use. At present, there are several hundred different types of radioactive material package designs that have been authorized, ranging in size from small packages weighing a few pounds to massive casks weighing over 100 tons.

ACCIDENT STATISTICS

Accidents occur in a range of frequencies and severities. Most accidents occur at low vehicle speeds; the severity of accidents is greater at higher speeds but the frequency decreases as the severity increases. Accidents generally involve some combination of impact, puncture, or fire effects.

Truck. In 1969, large motor carriers reported[21] a total of 38,813 accidents involving death, injury, or property damage in excess of $250. The accidents included 19,682 injuries, 1,497 fatalities, with an overall accident rate of 2.5 accidents per million vehicle miles. For hazardous materials shipments, the accident rate was 1.7 per million vehicle miles. Fifty percent of the reportable accidents involved collision with autos or buses, 15.5% collisions with other trucks, 14% collisions with fixed objects, and 0.6% collisions with trains. 9.5% were roll-overs or run-offs, and 11.4% other types of accidents. Fire occurred in 1.37% of the reportable accidents.[22]

In truck accidents, severe damage to packages may be encountered in all types of accidents. Impacts which are likely to be most damaging are those on stationary, rigid objects, such as concrete abuttments or bridge structures. In collisions with an object, yielding or crushing of the vehicle or the object with which the vehicle collides reduces the impact received by the package. Roll-overs usually occur at higher speeds, and must be considered as potential contributors to major damage of a package.

A study in 1960[23] showed the following percentages of accidents for the four ranges of truck speeds given. We have assumed those percentages apply to the four ranges of speeds used in our analysis of 0-30, 30-50, 50-70 and >70 mph.

TABLE 1

Type of Accident	Speed in MPH			
	0-32	32-52	52-72	>72
All accidents	23.7%	56.0%	19.8%	0.5%
Collisions with autos and buses	34%	42%	23%	1%
Collisions with other trucks	25%	72%	3%	0.1%
Overturns and other collisions	8%	69%	23%	0%

Truck fire data[21] [22] indicate that fire is involved in about 0.8% of truck-truck collisions, 0.3% of the truck-auto collisions, 0.6% of truck-fixed object collisions, 2% of the truck-train collisions, and 1% of the roll-over/run-off accidents. Most fires involve only the fuel from the vehicle fuel tanks, and last less than 1/2 hour, unless other freight becomes involved. Only in the case of truck-truck collisions is there likely to be a larger supply of fuel involved, e.g., a collision with a gasoline tank truck or a truck loaded with paint. Some fires start from overheated tires or accidental ignition of cargo. Truck-auto, truck-bus, and single vehicle accidents were considered to be essentially free of fires lasting longer than 1/2 hour.

It is assumed that only in truck-truck accidents is there a credible likelihood that fires would occur which could involve radioactive materials and which could last more than 1/2 hour, and then only when one of the trucks is carrying significant amounts of flammable liquids as cargo (e.g., tank trucks of gasoline or LPG; or van trailers carrying barrels of paint). For lack of data on the percentage of trucks carrying flammables, it is conservatively assumed that at least one of the trucks in each truck-truck accident is carrying flammable cargo. Of all truck accidents, 15.5% involve other trucks, i.e., are therefore truck-truck accidents having a potential for long fires.

Of the fires which do occur, it has been estimated[23] that 1% of the fires last more than one hour, 10% last between 1/2 hour and one hour and the balance, 89%, last less than 1/2 hour. Although there are truck fires in transport which last for several days, in most cases these involve the burning of only small amounts of fuel per unit time, and are of little consequence in terms of heat output.

The probabilities for truck accidents are listed in Table 3.

Rail. In 1969, for a total number of car miles of about 61 billion, the rail industry reported[24] a total of 8,543 accidents involving death, injury, or property damage in excess of $750, of which 4,971 were other than grade-crossing accidents. The accidents included 23,356 injuries, 2,299 fatalities. The overall accident rate is 0.15 train accidents per million car miles. The accident rate for other than grade-crossing accidents is 0.08 train accidents per million car miles. Each accident involves an average of 10 rail cars, so the accident rate per car for other than grade crossing accidents would be about 0.8 car accidents per million car miles. Twenty-one percent of the reportable accidents were collisions, 70% were derailments, and 9% were other types of accidents. About 1.5% of the rail accidents involved fire, most of them occurring in serious derailments in overland movements.

In rail accidents, severe damage to the cargo may be encountered in both collision and derailment type accidents. Rail-grade crossing accidents (train-truck or train-auto) rarely involve significant damage to cargo. Other collision type accidents which do not cause derailment are not likely to involve significant damage to a package. Accidents which have the highest probability of producing significant damage to shipment containers are those involving overland derailment accidents which involve either impact of the packages on forward cars, or impact on the packages by rearward cars.

The accident rate of 0.8 car accidents per million car miles for other than grade crossing accidents was used as the probability of a railroad car carrying a shipment being involved in an accident that might cause damage to that shipment.

An unpublished study by the DOT of the total accidents that occur at various speeds indicates that 58.5% of all train accidents occur at a speed less than 30 miles an hour, 32% occur at a speed between 30-50 miles an hour, 9.4% occur between 50-70 miles an hour, and 0.1% occur at speeds exceeding 70 miles an hour.

Fires other than those involving ruptured tank cars or flammable liquids are unlikely to last longer than 1/2 hour, due to lack of sufficient fuel. Data relating major fires to train speed are sparse. It is estimated that 1.5% of all rail accidents involve fires of which 85% last less than 1/2 hour, 14% last between 1/2 hour and 1 hour, and 1% of the fires last more than 1 hour.

The probabilities for rail accidents are listed in Table 3.

<u>Barge</u>. Records[25] for fiscal year 1970 for domestic waterborne traffic show a total of 506 billion ton-miles of water traffic with 548 cargo barge accidents reported. Data are not available to indicate the fraction of those ton-miles due to barge traffic. We estimated the total barge ton-miles to be 380 billion. According to the Coast Guard report, miscellaneous types of vessels, including cargo barges, were involved in accidents which resulted in 33 injuries and 33 fatalities during that period.

The available data does not lend itself to an analysis equivalent to that for rail or truck transport. On the basis of discussions with the U.S. Coast Guard, it is assumed that the average net (cargo) weight of a typical barge is about 1,200 tons. The total number of barge-miles would then be about 310 million. This yields an accident rate of about 1.8 accidents per million barge miles.

There are very few data available on the severity of accidents involving barges. Barges travel only a few miles per hour; therefore, the velocity of impacts in accidents would be small. Because of the large mass of the vehicle and cargo, severe impact forces could be encountered by packages (spent fuel casks) aboard barges. A forward barge could impact on a bridge pier and suffer crushing forces due to other barges being pushed into it. A coastal or river ship could knife into a barge. Fires could result in either case. An extreme accident, i.e., an extreme impact plus a long fire, is not considered credible. The likelihood of a long, severe fire in barge accidents is small because of the availability of water at all times. Also, since casks could be kept cool by sprays or submergence in water, loss of mechanical cooling can be compensated for.

The likelihood of cargo damage occurring in a barge accident is much less than in the case of rail accidents. For purposes of this analysis, and based on U.S. Coast Guard data, it is estimated that about 90% of the barge accidents would result in minor or no damage to the cargo, and would not involve fires. Moderate cargo damage due to impact would result in 8% of the barge accidents and severe damage in 2%. Fire would be likely only in those accidents involving moderate or severe cargo damage, and it is estimated that the likelihood of a fire in severe accidents would be 10 times that in moderate accidents. Based on the 1970 data, with only one cargo fire reported, it is estimated that fire would occur in 0.7% of the moderate accidents and 7% of the severe accidents. There are no data on the duration of fires in barge accidents so we arbitrarily used the rail figures of 85% of all fires lasting less than 1/2 hour, 14% lasting between 1/2 and 1 hour, and 1% lasting more than 1 hour.

The probabilities for barge accidents have been incorporated into Table 3.

ACCIDENT SEVERITY IN TERMS OF PACKAGE DAMAGE

The amount of damage to a package in an accident is not always directly related to the accident severity; that is, in a series of accidents of the same severity, or in a single accident including a number of packages, the amount of damage to the packages involved will vary from no damage to extensive damage.

Various factors limit the effect accident conditions will have on a package.(15) In relatively minor accidents, serious damage to packages can occur due to impacting on sharp objects or by being struck by other cargo. Conversely, in extreme accidents, damage to some packages may be minimal. In some cases, the packages may be thrown free of the impacting vehicles or be so located in the vehicle that they are unaffected by the impact or the fire that ensues. Package damage depends on the form and amount of energy sustained by the package and the ability of the package to withstand those forces. The form and amount of the energy transmitted to the package in an accident depend on several factors which vary according to the accident circumstances and which have not been well documented or analyzed.

The ability of a package to withstand accident forces depends both on the design of the package and the quality assurance exercised in its manufacture, use, and maintenance. We assumed, for purposes of this study, that normal quality assurance practices were followed.

Severe transportation fires seldom last more than 1/2 hour, except in ships and storage depots,[9] because either the fuel is exhausted or the fire is extinguished by fire fighting crews. Although flame temperatures of liquids, such as jet fuel or kerosene, may reach 1800°-2000°F, such peak temperatures are reached only very locally on the surface of material involved in the fire. Only under very unusual circumstances is more than 50% of a package surface likely to be exposed to the flame for as long as 1/2 hour. Even in a longer fire, the package may be in a location where the fire has little or no effect on it.

In the table below, accidents are categorized by degree of severity in terms of velocity of vehicle impact and incidence and duration of fire.

TABLE 2

Accident Severity Category	Vehicle Speed at Impact (mph)	Fire Duration (hr)
1. Minor	0-30	0-1/2
	30-50	0
2. Moderate	0-30	1/2-1
	30-70	<1/2
3. Severe	0-50	>1
	30-70	1/2-1
	>70	0-1/2
4. Extra Severe	50-70	>1
	>70	1/2-1
5. Extreme	>70	>1

The next step was then to take the various data selected and apply them to the specific accident severity categories. The results are summarized in Table 3 below. Copies of the detailed calculational work sheets are available free of charge from the author.

TABLE 3

ACCIDENT PROBABILITY

Severity Category	Vehicle Speed (mph)	Fire Duration (hr)	Probability per Vehicle Mile: Rail	Truck	Barge*
Minor	0-30	<1/2	$6x10^{-9}$	$6x10^{-9}$	--
	0-30	0	$4.7x10^{-7}$	$4x10^{-7}$	$1.6x10^{-6}$
	30-50	0	$2.6x10^{-7}$	$9x10^{-7}$	$1.4x10^{-7}$
Total			$7.3x10^{-7}$	$1.3x10^{-6}$	$1.7x10^{-6}$
Moderate	0-30	1/2-1	$9.3x10^{-10}$	$5x10^{-11}$	--
	30-50	<1/2	$3.5x10^{-9}$	$1x10^{-8}$	$8x10^{-9}$
	50-70	<1/2	$9.9x10^{-10}$	$5x10^{-9}$	$2x10^{-9}$
	50-70	0	$7.5x10^{-8}$	$3x10^{-7}$	$3.4x10^{-8}$
Total			$7.9x10^{-8}$	$3x10^{-7}$	$4.4x10^{-8}$
Severe	0-30	>1	$7.0x10^{-11}$	$5x10^{-12}$	--
	30-50	>1	$3.9x10^{-11}$	$1x10^{-11}$	$9.3x10^{-11}$
	30-50	1/2-1	$5.1x10^{-10}$	$1x10^{-10}$	$1.3x10^{-9}$
	50-70	1/2-1	$1.5x10^{-10}$	$6x10^{-12}$	$3.3x10^{-10}$
	>70	<1/2	$1x10^{-11}$	$1x10^{-10}$	--
	>70	0	$8x10^{-10}$	$8x10^{-9}$	--
Total			$1.5x10^{-9}$	$8x10^{-9}$	$1.6x10^{-9}$
Extra Severe	50-70	>1	$1.1x10^{-11}$	$6x10^{-13}$	$2.3x10^{-11}$
	>70	1/2-1	$1.6x10^{-12}$	$2x10^{-13}$	--
Total			$1.3x10^{-11}$	$8x10^{-13}$	$2.3x10^{-11}$
Extreme	>70	>1	$1.2x10^{-13}$	$2x10^{-14}$	--
Total			$1.2x10^{-13}$	$2x10^{-14}$	--

*Barge accident probabilities are based on the duration of the fire and actuarial data on cargo damage. The impact velocities of all barge accidents were considered to be less than 10 mph, but for the purposes of this table, minor cargo damage is assumed to be equivalent to land vehicle impact speeds of 0-30, moderate cargo damage 30-50 and severe cargo damage 50-70.

ANALYSIS OF RESULTS

If we now go back to the original question regarding which mode of transportation is safest, we find we must now ask another question, "Safest against what?" In looking at Table 3, we see that the probability of minor accidents which might sffect the cargo is the lowest for rail. We have to just accept that all of our freight will go through the types of shocks, vibration, jolts, bangs, snd bumps that are routine in transportation today.[16] But let's sssume a situation whereby one cannot afford to protect against a total loss of freight in a serious accident, but would like to ship things in a way which would avoid as much minor damage as possible. Would one be better off by truck or rail? Table 3 shows that the probability of a minor truck accident is about twice that for a minor rail accident - 1.3 per million miles for truck vs. 0.7 for rail. So, rail presents s lower risk of minor accidents than truck. Barge is slightly higher than truck.

Let's look at the other end of the scale. If one picks a mode of transportation that has the lowest risk of s catastrophic accident, pick highway - six times better than rail.

But now let's be realistic. The errors inherent in the overall results, hsving selected only certain data with which to work, are probably greater than those differences of two or six. Perhaps the only meaningful conclusion we can draw from the analysis is that there really isn't all that much difference between the various modes, and a single figure could be chosen for each of the accident severity categories which would be useful for general assessments of the likelihood of accidents. These values are given in Table 4.

TABLE 4

ACCIDENT PROBABILITIES FOR TRUCK, RAIL, AND BARGE IN ACCIDENTS PER VEHICLE MILE FOR THE ACCIDENT SEVERITY CATEGORIES

Minor	Moderate	Severe	Extra Severe	Extreme
1×10^{-6}	3×10^{-7}	8×10^{-9}	1×10^{-11}	1×10^{-13}

MEANING OF RESULTS

What do the figures in Table 4 mean? Let's take an example. If one has to make a shipment of 1000 miles, the probability that the shipment will be involved in a severe accident is $1000 \times (8 \times 10^{-9})$, or about 8×10^{-6}. That's 8 chances in a million! The chances that it will be involved in a minor accident is about 1 in a thousand. If one makes a thousand such shipments, one of them can be expected to be in a minor accident.

Now, how can we relate those figures to some measure we might be able to relate to emotionally? If each American moves 10,000 miles each year by auto, they travel about 2×10^{12} (2 trillion) people-miles each year. With about 6×10^{4} (60,000) highway deaths each year, the probability of a highway death per mile is $(6 \times 10^{4}) \div (2 \times 10^{12})$, or about 3×10^{-8}. That's about halfway between the Table 4 figures for moderate and severe accidents. In other words, there's about 4 times the likelihood that the reader of this paper will be killed on a 1000-mile trip than for the 1000-mile shipment to be involved in a severe accident. Yet few of us hang back from taking a 1000-mile trip because of the likelihood of our being killed.

Eight chances in a million. That's a very small number, and a very low probability. Just to place perspective on this number, let us look at a couple of examples. Eight parts per million would make an interesting martini. That's about ten jiggers of vermouth in a railroad tank car of gin. Ah, yes, but that probability is still there, one might say. But then, if Caesar's dying breath were dispersed evenly throughout the atmosphere, there would still be one molecule for everyone who has lived on earth in the past 2,000 years. The numbers are very small - small enough to be considered incredible? Perhaps.

Let's compare those results with more common consequences - death or injury, primarily to truck drivers. For common injuries, the truck injury rate is 9×10^{-7} per truck mile. For rail, it is 3.6×10^{-6}, and for water it is 9×10^{-8}. For deaths, the comparable values are 6.6×10^{-8}, 7.3×10^{-7}, and 9×10^{-8}. In other words, for a truck shipment, it is 8 times more likely that there will be a death not due to any radiological effects than there will be any severe damage to the packages in the shipment. The non-radiological consequences in every case far outweigh the radiological consequences.

ESTIMATES OF PACKAGE DAMAGE

The following classification of package damage in terms of breach of containment was used in this analysis.

1. No breach - no damage. No damage or only superficial damage which does not affect the general transportability of the package. Successive shipments could be made without repairs.

2. No breach - minor damage, no repair required. The outside of the package may be damaged such that it is obvious that it has been involved in an accident, e.g., paint burned off or the corners mashed in. None of the safety features important to continued functioning of the package is adversely affected and the package could continue to its destination without repair.

3. No breach - moderate damage, repairs required. The package may be damaged such that certain features related to the effectiveness of the package's shock or puncture resistance or fire protection capabilities may have been adversely affected. The shielding or spacing for nuclear criticality safety may have been affected. Containment is not breached and the radioactive material may be safely left in the container without repair for some period of time (weeks perhaps). Some repair would be necessary, however, for continued transport of the package, or some operating procedures substituted for the reduction in safety features.

4. Small breach - severe damage. Damage may include a minor breach in the containment, some loss of shielding or spacing. This damage may result in small releases of gases or liquids (e.g., some coolant), but no significant loss of contents.

5. Medium breach - extra severe damage. Damage may include a partial loss of containment, a significant loss of shielding or spacing, or damage to heat transfer media (e.g., auxiliary cooling systems) which may lead to loss of containment or shielding. This damage may result in loss of most of the free gases and liquids (e.g., the coolant) and a release of a small fraction of the available contents.

6. Large breach - extreme damage. Damage may include a total loss of containment, loss of most of the shielding or spacing, loss of heat transfer media. This may result in release of some (a few percent?) of the available contents, and loss of neutron moderaters and poisons.

For the purposes of this analysis, we estimated the fraction of packages expected to be damaged to the extent specified in the classes discussed above in each of the accident severity categories. Those estimates, based on gross judgment and the very limited data available, are given in Table 5.

The estimates of package damage fractions should take into account package design, shipment experience,[26] package test results,[27] and vehicle test results.[17] The fractions should be chosen on the basis that some serious package damage may occur in all types of accidents, and that serious damage is more likely to occur in a severe accident. In any accident, some of the packages may not be damaged at all, and a large fraction will be undamaged in the minor accidents. Further, accident resistant packages are unlikely to be damaged to the extent that there is a breach of containment in accidents no more serious than the severe category which they are specifically designed to withstand.

For example, in a hypothetical series of accidents in the severe category involving truckloads of standard 55-gallon steel drums with normal loads (300-600 pounds), perhaps half of them might be slightly damaged but without any breach of containment; another third might have a small breach, a tenth a moderate breach, and only a percent or somewhere the total contents might be released. If the same drums were overpacked in a steel or wooden accident-resistant jacket of some sort, perhaps 99 percent would be leak-free, and only one percent of them would have any kind of leakage at all. Even with the leakers, most of them would involve small leaks rather than serious leaks, and the likelihood of total release is probably too small to be calculable, or even credible. These two examples are shown in Table 5. It must be recognized that, in these examples, a highly stylized approach was used, and the numbers are more arbitrary than precisely accurate. For that reason, the values shown may be valid to within a factor of only three to five.

Damage fractions would differ widely for different package types. For specific package designs, the values could probably be estimated with a degree of accuracy somewhat better than three to five.

The probabilities of package damage per vehicle mile for the various accident severity categories given in Table 6 were calculated by multiplying the accident probabilities in the various severity categories given in Table 4 by the estimated fractions of packages damaged given in Table 5. As indicated by the values shown in Table 5, severe damage to the package is more likely to occur in the more severe accidents and less likely to occur in the less severe accidents. At the same time, it should be recognized that there is some calculable probability of severe damage to packages involved in minor accidents.

TABLE 5

PREDICTED FRACTION OF PACKAGES DAMAGED
VS.
ACCIDENT SEVERITY

Postulated Damage	Accident Severity Category				
	Minor	Moderate	Severe	Extra-Severe	Extreme
Steel Drums					
No Breach	0.90	0.80	0.55	0.25	0.10
Small Breach	.07	.15	.30	.25	.10
Medium Breach	.02	.03	.10	.30	.30
Large Breach	.01	.02	.05	.20	.50
Steel Drums Plus Overpack					
No Breach	0.99+	0.99+	0.99	.95	.90
Small Breach	<.001	<.01	.01	.04	.07
Medium Breach	-	-	.001	.01	.02
Large Breach	-	-	-	.001	.01

TABLE 6

PROBABILITY OF DAMAGED PACKAGES PER VEHICLE MILE

Degree of Damage	Accident Severity: Minor	Moderate	Severe	Extra-Severe	Extreme	Total
Steel Drum						
No Breach	9×10^{-7}	2×10^{-7}	4×10^{-9}	3×10^{-12}	1×10^{-14}	1×10^{-6}
Small Breach	7×10^{-8}	5×10^{-8}	2×10^{-9}	3×10^{-12}	1×10^{-14}	1×10^{-7}
Medium Breach	2×10^{-8}	9×10^{-9}	8×10^{-10}	3×10^{-12}	3×10^{-14}	3×10^{-8}
Large Breach	1×10^{-8}	6×10^{-9}	4×10^{-10}	2×10^{-12}	5×10^{-14}	2×10^{-8}
Steel Drum Plus Overpack						
No Breach	1×10^{-6}	3×10^{-7}	8×10^{-9}	1×10^{-11}	9×10^{-14}	1×10^{-6}
Small Breech	1×10^{-10}	3×10^{-10}	8×10^{-11}	4×10^{-13}	7×10^{-15}	5×10^{-10}
Medium Breech	*	*	8×10^{-12}	1×10^{-13}	2×10^{-15}	8×10^{-12}
Large Breach	*	*	*	1×10^{-14}	1×10^{-15}	1×10^{-14}

*Too small to calculate.

Another way to calculate the probability of breaches of containment is to take a more simplistic and less accurate approach - that of assuming that all packages of a similar type will react identically in similar accidents. For example, we could assume that simple steel drums would withstand minor accidents, suffer small breaches in moderate accidents, medium breaches in severe accidents, and large breaches in extra-severe or extreme accidents. Also, the accident resistant drum packages would withstand minor, moderate, and severe accidents without leakage, would suffer small breaches in extra-severe accidents, and medium breaches in extreme accidents. In other words, we assume a value of 1 for the probability of the comparable degrees of package damage in each of the accident severity categories. These results are also shown in the last two columns of Table 7 for comparison.

TABLE 7

PROBABILITY PER VEHICLE MILE OF AN ACCIDENT
IN THE DEGREE OF PACKAGE DAMAGE SPECIFIED

Degree of Package Damage	From Table 6 - Totals		From Table 4 - assuming probability of 1 for package damage	
	Steel Drum	Steel Drum + Overpack	Steel Drum	Steel Drum + Overpack
No Breach	1×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-6}
Small Breach	1×10^{-7}	5×10^{-10}	3×10^{-7}	1×10^{-11}
Medium Breach	3×10^{-8}	8×10^{-12}	6×10^{-9}	1×10^{-13}
Large Breach	2×10^{-8}	1×10^{-14}	1×10^{-11}	-0-

It will be noted that there is a significant difference in the two sets of values for the more serious accidents. It could be deduced then that for calculating the probabilities of package damage for minor and moderate accidents, it might not be worthwhile to bother with detailed estimates of package damage fractions as shown in Table 6. However, for the more serious accidents, analysis of the particular mode of failure to determine package damage fractions might be much more realistic in terms of a conservative approach to the analysis.

The analysis shows (Table 4) that the frequency of severe accidents for shipments is about one for each 120 million vehicle miles. The probability of extremely severe accidents is about 80,000 times less. Relating back to the case of a nuclear power reactor, and assuming some typical transportation mileages,[5] the analysis allows us to estimate that the predicted likelihood of serious leakage arising from accidents involving shipments of radioactive materials (such as spent reactor fuel elements) per nuclear power plant per year is not more than one in 30 million. By comparison, the likelihood of serious injury due to an automobile accident per person per year is about one in 500.

CONCLUSION

On the basis of the analysis described in this paper, it may be stated that the theoretical probability of occurrence of almost any kind of transportation accident situation can be estimated with a reasonable degree of accuracy. The methodology shown may be extended to different types of accidents or different types of accident consequences in terms of damage to different types of packages.

With regard to the probability of serious public consequences of transportation accidents involving radioactive materials, it appears that the probability of death, injury, or massive property loss due to transportation of radioactive materials is (1) determinable; (2) not zero; and (3) very small. In projecting the total accident probability for transportation of radioactive materials to and from nuclear power plants, it seems obvious that the radiological consequences of the total accident spectrum will be several orders of magnitude below the more common nonradiological causes.

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Appendix A

POTENTIAL SAFETY IMPACT OF DOT LEGISLATIVE PROGRAM, NOVEMBER 1971

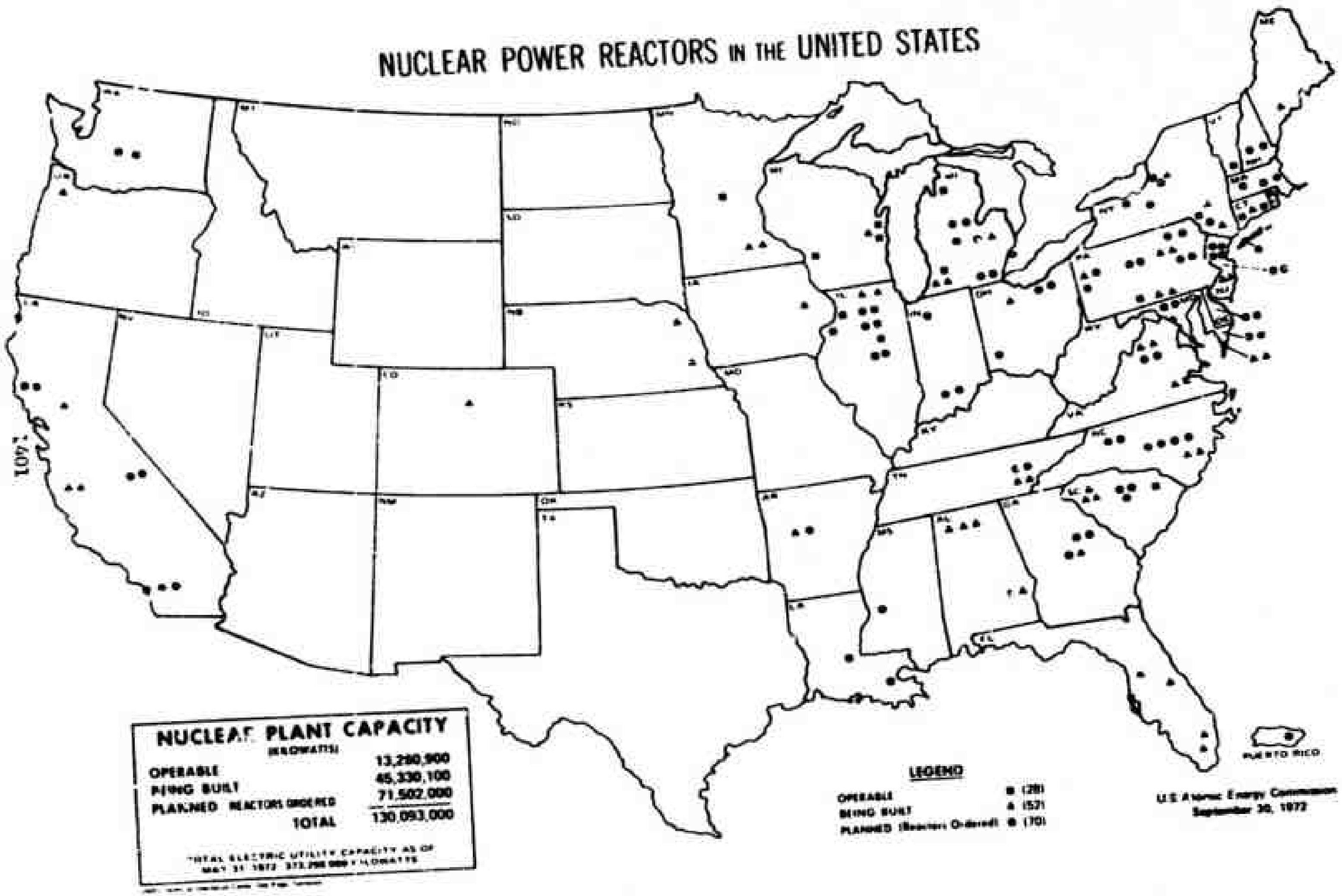
Projected 1980 Freight Traffic	Billion[29] Ton - Miles	Fatalities[30] per Year	Injuries[28] per Year
Without Regulatory Changes			
Rail	967	2,417	19,340
Water	802	249	2,262
Motor	537	5,853	70,186
Total	2,306	8,519	91,784
With Regulatory Changes			
Rail	1,033	2,583	20,660
Water	802	249	2,262
Motor	471	5,134	61,560
Total	2,306	7,966	84,482
Difference		553	7,302

THE POTENTIAL SAFETY IMPACT OF RAILROAD INSTITUTIONAL CHANGES

	Change Inducing Traffic Diversion		
	Rate Deregulation	Improved RR Service	Totals
Percentage of intercity highway traffic diverted from highway to railroad by change	25%	40%	65%
Billion ton-miles diverted (per year)[31]	92.2	147.5	239.7
Safety Impacts (per year)			
Reduced Highway fatalities[30]	1003	1608	2613
Increased Railroad fatalities[30]	230	369	599
Net saving to society (deaths postponed)	775	1239	2014
Reduced Highway Injuries[28]	12,050	19,281	31,331
Increased Railroad Injuries[28]	1,844	2,950	4,794
Net saving to society (injuries avoided)	10,206	16,331	26,537

Appendix C

NUCLEAR POWER REACTORS IN THE UNITED STATES



No. P-332
Contact: Clare Miles
Tel. 973-7771

FOR IMMEDIATE RELEASE
(Friday, October 13, 1972)

AEC ANNOUNCES AVAILABILITY OF DRAFT ENVIRONMENTAL STATEMENT ON PROPOSED FORKED RIVER NUCLEAR POWER PLANT IN NEW JERSEY

The Atomic Energy Commission is issuing for comment a draft environmental statement related to construction and operation of Jersey Central Power & Light Company's proposed Forked River Nuclear Generating Station, Unit 1, in Ocean County, New Jersey.

Under AEC's regulations implementing the National Environmental Policy Act (NEPA), the Commission is responsible for evaluating the total environmental impact of nuclear power plants and for assessing this impact in terms of available alternatives and the need for electric power.

The Commission is seeking comments from Federal, State and local agencies as well as from interested members of the public. After receipt of the comments, a final environmental statement will be prepared by the AEC Regulatory Staff which will contain a conclusion as to whether a construction permit should be issued or conditioned appropriately to protect environmental values. Comments should be sent within 30 days (by November 13, 1972) to the Deputy Director for Reactor Projects, Directorate of Licensing, U. S. Atomic Energy Commission, Washington, D. C. 20545.

Copies of the draft statement will be available for inspection at the Commission's Public Document Room, 1717 H Street, N.W., Washington, D. C., and at the Ocean County Library, 15 Hooper Street, Toms River, New Jersey. Copies may be obtained by writing to the Deputy Director for Reactor Projects, Directorate of Licensing, U. S. Atomic Energy Commission, Washington, D. C. 20545.

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No. P-333
Contact: James D. Lynam
Tel. 973-3446

FOR IMMEDIATE RELEASE
(Tuesday, October 17, 1972)

NOTE TO EDITORS AND CORRESPONDENTS:

Following is a brief status report on the U. S. civilian nuclear power program as of September 30, 1972:

During the first three quarters of this year, electric utilities made known plans for 31 nuclear power generating units with a total capacity of 33,664,000 kilowatts to be located at 18 power stations. Reactor suppliers were selected for 13 of these units and for nine previously announced.

In the first three quarters of 1971, utilities made known plans for 25 nuclear power generating units with a total capacity of 23,617,000 kilowatts to be located at 12 power stations. Reactor suppliers have been selected for 20 of these units and for one announced in 1967.

Status of nuclear power generating units, as of September 30, 1972

		Kilowatts
38	operable	15,260,000
52	being built	45,330,100
70	planned (reactors ordered)	71,501,000
160		130,093,100

Enclosed for your information is a map of the United States showing the location of all present and proposed civilian nuclear power generating units for which reactor suppliers have been selected.

Enclosure

STORAGE AND HANDLING OF OXIDIZING CHEMICALS

W. H. Doyle
Factory Insurance Association
Hartford, Connecticut

What I have to say today has to do with the fringe areas of explosive problems. I am talking as a representative of the National Fire Protection Association. With a name like that, obviously, explosion hazards are secondary. However, the NFPA does have a committee on Chemicals and Explosives. Our chairman is Dr. Robert W. Van Dolah of the Bureau of Mines and his major interest is in the explosives area. In addition to being chairman of the committee as a whole, he is chairman of the sectional committee on Rocket Propellants. Our other sectional committees are Chemistry Laboratories, Electrical Equipment in Chemical Atmospheres, Explosives (chaired by Harry T. Rittman of duPont), Properties of Hazardous Chemicals and Storage, Haudling and Transportation of Hazardous Chemicals where I act as sectional committee chairman.

With the growth of the plastics industry, there was a consequent increased use of organic peroxides as reaction activators. There were many industrial accidents involving this use but they were mostly of small consequence. There have, however, been some sizable accidents in the manufacture of organic peroxides and a few involving their transportation. The first manufacturing accident that really made the headlines involved the production of tertiary butyl peracetate. 11 men were killed and 37 injured. Where about 3,000 lbs. of the product in glass carboys had been stored near the process equipment, there was a large crater. Following this accident, the National Board of Fire Underwriters (now the American Insurance Association) prepared their Research Report No. 11 in 1956. This collected most of the organic peroxide accidents of any consequence and proposed safe storage and handling practices. The booklet was prepared with the cooperation of peroxide manufacturers and Dr. McKenna of the Bureau of Explosives, Association of American Railroads. However, the accident seems to have occurred (all who knew were killed) because of some sort of manufacturing error and the NFPA does not speak to manufacturing processes.

In connection with transportation, I must point out that our sectional committee function with respect to transportation is nominal rather than real. Transportation of hazardous chemicals, interstate, has always been regulated by governmental agencies so the usual committee action is to require that intrastate transportation be in accordance with Federal regulations. Since many of our political subdivisions adopt the NFPA standards as part of their fire protection codes, this has the effect of extending Federal regulations to situations that might otherwise lack legal control. It was, however, largely as a result of a transportation accident that the sectional committee was saddled with the task of trying to do something about oxidizers. This accident occurred in 1962 in Norwich, Connecticut. A trailer truck was delivering a load of mixed organic peroxides from the Western New York area to a distribution warehouse. Unloading of the trailer had been started when smoke was noticed coming from the front in the area where there were 60 drums and 20 cartons of MEK peroxide. The fire department was called and, when they arrived, were warned that the cargo was dangerous. Just as they were starting to discharge water through the rear door of the trailer on to the fire, the cargo exploded. Four firemen were killed and four others injured. This accident convinced most of us that the NFPA should become involved in developing a standard for the handling of hazardous chemicals.

Accordingly, the then sectional committee chairman, Ray Hill, Assistant Chief of the Los Angeles Fire Department and on the Board of Directors of NFPA working through a group of West Coast fire marshals and fire chiefs, put together a draft of such a standard. This was a very ambitious undertaking. NFPA had issued a memorandum 704-M which suggested a method of marking containers of chemicals and buildings housing chemicals with a system involving a diamond with numerals 0 through 4 in each of three spots on the diamond to indicate the degree of hazard with respect to fire, toxicity and self-reactivity. The working committee draft followed this approach. Within the sectional committee, as a whole, the draft created much consternation because

its members felt they lacked any reasonable degree of competence in assessing toxicity hazards. However, subcommittees worked on these various facets. This working continued, off and on, for four years. Ray Hill then resigned from the sectional committee because he had been appointed chief of the Los Anglea Dept. and I was picked as chairman. At that time we decided to break the problem down into bitesize chunks. Since organic peroxidea were listed partly as flammable solids and partly as oxidizers, we addressed ourselves to the preparation of a code for the storage and transportation of oxidizing materials and organic peroxides. A draft of this code was presented to the NFPA annual meeting in New York in May 1969 for adoption as a tentative standard. NFPA procedure is to adopt material as tentative in order to get circulation and comments and that is what we got. It became obvious from the comments that any attempt to treat both oxidizers and organic peroxides in a single publication could not succeed so we set one subcommittee to work on liquid and solid oxidizing materials and another to deal with organic peroxides with a view to producing two separate documents.

The subcommittee considering organic peroxides found themselves in a maze instead of following a path. In 1965, the American Society for Testing and Materials had issued Special Technical Publication No. 394, "Fire and Explosion Hazards of Peroxy Compounds." In 1966, the National Board of Fire Underwriters, by now changed to the American Insurance Association, issued a revision of their Research Report No 11. In the meantime, the Safety Committee of the Plastics Industry was developing tests and a classification system based on these tests. The Factory Mutuals developed guidelines based on this approach and issued them in 1969. During this same period, the United Nations formed a committee to study the problem and at least two international discussions were held. These groups are advocating variously 5, 4 and 3 divisions for classifying organic peroxides and a large gamut of tests to determine their hazards and assist in the classification. Initially, opinions within the subcommittee ranged from the ultraconservative "organic peroxides all resemble TNT" to "with minor exceptions, organic peroxides are as safe as mother's milk."

Convergence of these opinions was slow. We are now in some range less broad than black powder to cow's milk and, I believe, could quite readily reach a compromise solution if someone could develop a test or a method of analyzing existing tests which would permit extrapolation of the test results to give a feel for the effect of increase in mass.

While the organic peroxide problem that initiated the subcommittee work has lagged in its production of paper, the group involved in oxidizing chemicals produced a draft which was adopted as a tentative code in 1971, circulated and criticized and subjected to major operations and adopted in May of this year as another tentative code.

At a sectional committee in Boston three weeks ago, the comments received since May of this year were considered. Some changes were made and this revised draft is being circulated for subcommittee ballot. Those attending the meeting felt that the edited code will be suitable for adoption as a full fledged code, rather than tentative, at the May 1973 meeting of the NFPA. To those of you who may be interested in making comments, the full text of these revisions will be published by the NFPA in a volume containing all 1973 Technical Committee Reports. This will come out toward the end of this coming winter in time so that any objections can be presented to the committee prior to the May meeting and, if they are not satisfactorily resolved, be discussed on the floor of the meeting.

Parallel to the committee work, consideration to the problem of classifying oxidizers has been given by the Office of Hazardous Materials in the Department of Transportation. Under a DOT contract, the Bureau of Mines developed a test method for the classification of oxidizers. The result of this contract was Report of Investigations #7594, "Classification Test Methods for Oxidizing Materials," dated 1972. We do not quite have the problem faced by the subcommittee on organic peroxides but we do have an interesting divergence of approach.

In doing a rather limited literature search with respect to fires and explosions involving oxidizing agents, I found in the NFPA Quarterly for April 1909 a report of a fire in Minneapolis, Minnesota on March 19 of that year. It occurred on the sixth floor of a six-story brick building occupied as a wholesale durg house because of the "explosion" of a barrel of barium peroxide. Someone had bored into the barrel to obtain a sample. The boring produced not only shavings which mixed with the peroxide but also frictional heat which ignited the mixture. The damage amounted to some $50,000 and that was a lot of money in 1909. I mention this accident because, with the origin of the test concealed by the dusts of time, the Bureau of Explosives of the American Railroad Association began determining the fire hazard of oxidizers by mixing them with red oak sawdust and igniting the pile. As I understand it, the evaluation of the results was highly subjective. It occurs to me, however, that the old practice of shipping materials in wooden casks and the practice of boring in for samples may be why this test procedure was initiated. Also, barrels were generally of oak and red oak sawdust was used for the test. Perhaps this explains why the Bureau of Mines test procedure involves mixing the oxidizer, in various proportions including stiochiometric, with a special grade of red oak sawdust dried to a uniform state and igniting a bed of the mixture of specified dimensions. Measurement of the rate at which fire or decomposition goes through the mixture is then suggested as a measure of the hazard. By this method, the Bureau of Mines proposes that a Class I oxidizer material is one where the mixture burns at less than 10 in. per min. and that Class II consists of those whose mixtures burn at a higher rate.

A second test proposed by the Bureau of Mines involves liquid oxidizers. In this case, sawdust is put into a 200 cc. Pyrex beaker, heated to a predetermined temperature and the liquid oxidizer injected from behind a protective shield. The extent of reaction is determined from continuous temperature measurements and visual observations. If, in this test, the oxidizers ignite the sawdust

spontaneously when heated to something below 200°F and the burning produced is only moderate, the liquid material again falls in Class II. Oxidizers which, in this test, cause ignition at normal temperatures or vigorous burning at temperatures elevated to something less than 200°F are placed in Class III. This class also includes oxidizers capable of violent reaction when heated.

Class IV oxidizers are those which may detonate when mixed, or even unmixed, with combustibles if heated or subjected to shock.

The definitions proposed by the NFPA committee are that a Class I oxidizer is one whose primary hazard is that it increases the burning rate of combustible material with which it comes in contact. By this definition some of those rated as Class II by the Bureau of Mines would be included in Class I. We propose that a Class II oxidizer be one that causes spontaneous ignition when in contact with combustible materials. In Class III we have oxidizers that can undergo vigorous self-decomposition when catalyzed or exposed to heat and in Class IV materials that can undergo explosive reaction when catalyzed or exposed to heat, shock or friction.

The NFPA definitions were made with the intent that they would be used in considering storage situations and configurations. The guiding concepts are that solids in Class I can be stored in bulk on a concrete floor while solids in Class II would have to be stored in a container since accidental contact with combustible materials, such as might occur when piled in the open, could cause a fire. I have prepared a table showing how oxidizers are classified differently by the Bureau of Mines and the NFPA as a result of the differing approaches to classification.

One problem with the Bureau of Mines classification tests is they do not look at the transportation or storage system as a whole. The major problems faced by our committee have come up in areas where the system is involved.

I suspect that a rather large number of the people in this audience have an intimate acquaintance with the problem of maintaining swimming pool water

sufficiently germ-free so that it does not transmit pink eye, etc. The chemical of choice is calcium hypochlorite. When this dissolves in water, it produces the bleaching solution that does the sterlizing. However, when heated in the absence of water, it gives off oxygen. If an open container of the material is contaminated because of one of the children spills some coke into it or one of the adults spills a martini, the pure material takes off with considerable vigor and people have been burned or otherwise injured in this way. If this is shipped in a steel drum, the oxygen released escapes harmlessly. If it is in a fiber drum and the drum is involved in a fire, we have pure oxygen combining with a solid fuel and the result is spectacular. Going one step further, the material in the metal or fiber drum may be put up in subpackages enclosed in polyethylene film. In the table, I indicate that the decomposition temperature of calcium hypochlorite is about 100°C. When involved with a fiber drum or wood sawdust [the reported ignition temperatures of various cellulosic materials varying from 300°C to 410°C], much of the oxygen escapes. However, the temperature at which highly crystalline polyethylene melts is about 110°C which is about the decomposition temperature of the calcium hypochlorite. In the latter case, therefore, we have the equivalent of a JP-4-oxygen fire and that is worse than the fiber drum fire. Accordingly, we propose to define containers in such a way that those having polyethylene liners or containing plastic bags of the oxidizer are classed as combustible containers even though the actual shell may be of steel. I was recently told by a visitor from Imperial Chemical Industries in England that it is his practice to advise ICI on storage hazards on the basis of a test of the materials stored in contact with the containing system. It seems to me that this is an excellent approach.

It was largely because of in-depth consideration to the problems associated with calcium hypochlorite that the tentative code took its existing form. The heart of the code is, of course, a series of quantity distance tables. Of

necessity, calcium hypochlorite is stored in large quantities on the premises of the manufacturer and in warehouses under the control of the manufacturer. It is found in ever decreasing quantities on the premises of firms installing and servicing swimming pools and in the local hardware stores. The final revision of the code imposes greater restrictions on the amount that can be stored in the hardware store and gives the greatest latitude to storage on the manufacturer's premises. In the latter case, we have two storage concepts. One involves isolation of a certain maximum amount on the premise that a fire starting in this amount of storage in the permitted configuration will consume it all. The other approach calls for limiting the size of any one pile of containers and isolating these piles by good aisle space in a sprinklered building. The concept there is that the fire can be confined to a single pile.

Before leaving the subject of calcium hypochlorite, I should point out that there are two different animals going by the same name. The NFPA system calls hypochlorite over 50% by weight a Class III oxidizer but if it is less than 50% by weight or contains more than 35% calcium hypochlorite dihydrate by weight, we call it Class II. The hydrated material will react with the coke or the martini or the polyethylene film when heated but the heat of reaction is barely adequate to vaporize the water of hydration so the decomposition is not self-sustaining.

A second group of materials, which received considerable discussion at the last committee meeting, are trichloroisocyanuric acid and the sodium and potassium salts of diachloroisocyanuric acid. These materials are also used as swimming pool chemicals but they have broader applications in the fields of bleaching and sterilization. They all fell into Class I by the Bureau of Mines test with sawdust but the salts fell into Class III by the NFPA definition because they continue to decompose when decomposition is initiated by external heat. On the other hand, the trichloroisocyanuric acid does not continue to decompose after

decomposition ie initieted by hasting with a torch but, when contaminsted uith just the right amount of water, it releasae nitrogen trichlorida and thia is an explosive matarial which will ceusa spontanaous ignitic . Accordingly, the committee decided that this belonged in Class II rathar than Claee 1.

Under fire exposura conditions, tha salts of the chlorineted iso-cyanuric acids behave much differently from calcium hypochlorite. They decompose exothermically but the amount of heat released ie not eufficient to operate en ordinary sprinkler syetem but it is sufficient to csuse propegation throughout a warehouse of the material eseentially regardleer of esparation by aislae. In the past, etandards hava abdicated with raspact to the problem of etoring amounta adequate to permit economical manufecturing and distribution. The abdication takae the form of a atatemant eomething like, "The authority having jurisdiction may permit greater quantitiee or different configurations of etorage providad no distinct hazard to life or property resulte." This, in effact, eaye that the committee of praeumed experts doesn't know whet to say and wishes the local fire marehel better luck. However, one of the manufacturers of the isocyanuratee has developed a protection eystem involving emall open sprinkler systems turned on by heat detection devices. Testa hava ehown that thaea eystems will confine any dacompoeition to a eingle pila. Accordingly, we have phrased our exemption eomewhat differently. We eay, "The area and quantity of oxidizers in etorage may deviata from thase requiremente when the storega ie protactad by apacially enginearad fira protaction eyetems provan adaquata by taeze acceptable to the authority having jurisdiction." This approach gives the authority having jurisdiction some backgrouod for making ths necessary dacieion.

Returning to the tabla, I have included information on melting point and dacomposition temparatures where they wera available in the lateet edition of "The Handbook on Chemistry and Physics" by Chemical Rubber Publiehing Company.

This does not constitute much of a literature search but I am inclined to believe that decomposition temperature data for oxidizers are rare. I would welcome information from anyone who may have it.

Part of this problem of putting oxidizers in their proper slots will hopefully be solved by a constant temperature stability test method and a modified Differential Thermal Analysis method that will produce a pressure trace as well as a temperature trace. These procedures have been developed by ASTM Committee E-27 on the Hazard Potential of Chemicals and will appear for approval as tentative standards on an early ASTM ballot. Since E-27 is a small committee, I would like to ask that any ASTM members here vote affirmatively on these two when they are listed. We may need votes to reach the minimum required under ASTM procedures.

To sum up, the NFPA feels that guidelines are needed for the storage of oxidizing materials. We have prepared such guidelines and are in the final stages of the process of getting formal NFPA approval. This has been done inspite of sizable gaps in our knowledge. I justify this by quoting from William James - "We have to live today by what truth we can get today and be ready tomorrow to call it falsehood."

HAZARD CLASSIFICATION RATINGS FOR VARIOUS OXIDIZERS

TABLE I

Oxidizer	Bu. Mines	NFPA	MP°C	Decomp. Temp. °C
Ammonium Perchlorate......................	4	4	d	
Hydrogen Peroxide, >90-wt-pct aolution....	4			
Hydrogen Peroxide, >91-wt-pct aolution....		4		
Perchloric Acid, >72-wt-pct solution.......	4			
Perchloric Acid, >72.5-wt-pct aolution.....		4		
Chlorine Trifluoride......................	3	gas-not rated		
Calcium Hypochlorite, 69.5-wt-pct Cl_2......	3			100
Calcium Hypochlorite, over 50% by wt.......		3		100
Sodium Dichloroisocyanurate]..........	3		d	
Sodium Dichloro-a-Triazinetrione]..........		3	d	
Hydrogen Peroxide, 70-wt-pct solution......	3			
Hydrogen Peroxide, 52 to not more than 91-wt-pct solution......		3		
Perchloric Acid, 60 to 72-wt-pct solution..	3			
Nitrogen Textroxide.......................	3	gas-not rated		
Nitric Acid, 90-wt-pct aolution............	3			
Nitric Acid, more than 70 wt-pct solution..		2		
Sodium Peroxide...........................	3	2		460
Chromium Trioxide.........................	2	2	196	
Potaaaium Bromate.........................	2	2	434	370
Sodium Perchlorate........................	2	1	d	
Sodium Chlorate...........................	2	1	248	
Potassium Chlorate........................	2	1	356	400
Sodium Nitrate............................	2	1	307	380
Potassium Nitrate.........................	2	1	334	400
Potaaaium Permanganate....................	2	2	d	<240
Hydrogen Peroxide, 50-wt-pct aolution......	2			
Hydrogen Peroxide, 52 to not more than 91-wt-pct solution......		2		
Nitric Acid, 70-wt-pct aolution...........	2			
Nitric Acid, 70-wt-pct solution or less concentrated.................		1		
Lead Nitrate..............................	1	1	d	470
Silver Nitrate............................	1	1	212	444
Barium Nitrate............................	1	1	592	
Potassium Persulfate......................	1	1	d	<100
Potassium Dichromate......................	1	1	398	500
Hydrogen Peroxide, 30-wt-pct solution......	1			
Hydrogen Peroxide Solutions, over 8% but not exceeding 27.5% by wt............		1		

ULTRA HIGH SPEED FIRE PROTECTION SYSTEM FOR SOLID PROPELLANTS

Charles F. Averill
Grinnell Fire Protection Systems Co., Inc.
Providence, R. I.

At your 1960 seminar I had the privilege of announcing the development of a new ultra-high speed fire protection system.

In 1962, I gave an updated report with more detail and illustrations of actual installations.

I am pleased to have been asked again to bring you up to date.

There are now well over 200 installations of these special systems. Typical applications have been in the powder as well as the solid propellant field. Some of the hazardous equipment and operations that have been protected are:

- Vertical Mixers from 25-gallon to 300-gallon
- Casting and Curing Operations
- Slurry Mixing
- Strand Cutting
- Horizontal and Vertical Machining Operations
- Blocking Presses
- Conveyors and Ducts
- Pre-Roll and Final Roll Machines
- Even-Speed Roll Mills
- Sorting Tables
- Bagging and Sewing Operations
- Loading Stations
- I. R. Dryers
- and many others

I think it is safe to say that no other fire protection system has been called on to perform its intended function so soon after installation or in so high a percentage of cases. The very first system controlled a fire within a year of its installation.

It is impossible to quote exact figures on the number of systems that have operated on a fire since all such operations are not reported to us. However, it is safe to say that well over 30 per cent of the installed systems have operated on a fire. I know of no other type of fire protection system with a comparable record.

The principal reason for the success of this system is its extreme speed of operation. Water is applied to the fire in time intervals measured in milliseconds.

For those of you who may not be familiar with the system, its speed of operation is attained by the use of two (2) devices little used in the fire protection field before. The first is a solid state light sensitive cell, which gives us detection with the speed of light, and the second is an explosively actuated water control valve which releases line-pressure into the system in a few milliseconds.

The light sensing cells are sensitive to radiation in the near infrared range. These cells have the advantage of high sensitivity, small size, and low power requirements. They will, of course, respond to radiation from any source. There are so many sources of infrared radiation that the ambient light conditions must be carefully controlled.

Theoretically, any radiation detector responsive to any segment of the light spectrum, including ultraviolet, can be used. We have found the infrared to be best for most applications. However, each hazard should be evaluated individually, and the most suitable equipment used.

You will hear about ultraviolet detectors from another speaker so I will concentrate on infrared.

Selection and placement of the detectors is very important. They must have a line-of-sight view of the entire hazard being protected and be so placed that ambient light does not trigger them. This can present problems particularly where high levels of illumination are necessary for the operation of remote T. V. monitoring. However, with the help and cooperation of the buyer's operations people, we have been able to solve all these problems so far.

These detectors are photo conductive. Radiation from the flame reduces their resistance so that a current can flow. This current is magnified by a small transistorized amplifier and detonates a small primer in the water control valve.

To be successful in controlling a deflagration in the materials these systems are used on, large volumes of water must be quickly applied in a manner to completely envelop the fuel.

This is achieved by using a deluge system. That is, water is discharged from all outlets in the system at the same time, thus totally enveloping the hazard. To maintain the necessary speed of operation, it is essential that all piping be completely filled with water. Therefore, discharge nozzles that can be fitted with caps or plugs capable of holding priming water at atmospheric pressure must be used. The opening of the primer actuated water control valve imposes line-pressure on the priming water. This increase in water pressure blows off or ruptures the nozzle closures and water discharges from all outlets simultaneously.

We are often asked just how fast the system is. This is a difficult question because there is no one answer. For example, one of our installations operates in about 13 milliseconds whereas another operates in about 240 milliseconds.

A logical first question would be: How fast does water have to be applied in order to have a good chance for extinguishment? The logical second question is: How can we get water to the fire this fast?

The first question, by its nature, is directed to the manufacturer; the second question to the fire protection engineer.

The manufacturer will, of course, qualify his answer by citing the variables of type and geometry of hazardous material, the location and type of ignition mechanism, the initial temperature, degree of dryness, and the amount of confinement and consequent possible pressure build-up.

The gist of this is that it is virtually impossible to get a specific answer to the question of how fast water has to be applied in order to be effective.

This leaves the fire protection engineer without a finite target in his effort to produce rapid detection and water delivery. Without a specific target, we do the only logical thing and design our detection and water delivery to be as fast as possible within the limits of reliability and economic and physical feasibility and, in addition, we test as frequently as the availability of hazardous materials and facilities allows in order to develop a library of information.

Let's now consider some of the factors that affect the fire protection system operation time. We divide this time into two phases; one is the equipment operating time, that is the time from detection of the fire to the time this signal has been amplified and fired the primer in the water control valve.

The second phase is the time required from primer firing to the time water makes its exit from the fire protection nozzles.

The equipment operating time, as here defined, is the fastest phase and has a fairly constant value in our system in the order of 2 or 3 milliseconds.

The second phase of water delivery time is, of course, the source of most of the time consumption and is dependent on several factors. One of these factors is the completeness of water prime of the piping system from the explosive valve to the nozzle closures. Our tests show this to be a vitally important factor since, in general, an air pocket constituting about 5 percent of the total volume of the system will cause about a 100 percent increase in operating time.

Water supply pressure is another important factor in determining water delivery time. Both analysis and tests show that all other factors being equal, the water delivery time is inversely proportional to the square root of water supply pressure. This would mean, for example, that if the supply pressure on a specific system were increased from 50 PSI to 100 PSI, the water delivery time would be reduced by about 30 percent.

Since our test time are concerned with the period from water at rest to water exit from nozzles, frictional effects and coefficients obtaining during steady flow may or may not apply during unsteady flow. This problem is still being studies, but

fortunately most ultra high speed system designs are such that water delivery time, as defined, is practically independent of pipe line friction losses and almost soley due to inertia effects. We are, therefore, able to predict reasonably accurately what the fire protection system operating time will be provided we know the pertinent facts as to pressure, nozzle characteristics and pipe sizing and configuration.

In order to design the fastest feasible arrangement, we request of the manufacturer the following:

Proper ambient conditions for the photoconductive detectors.

Good water supply pressure.

Short and straight routes for the fire protection piping from water supply to nozzles.

Each installation is specially designed and tailormade for the individual hazard being protected.

Our usual procedure is to first determine by test that we can detect a fire in the fuel involved fast enough to be able to control or extinguish the fire. Then we make a survey of the equipment and, working with the Owner's engineers, select locations for the detectors, nozzles, control panel, water control valve, and piping so as not to interfere with the operation and still accomplish our purpose.

When there are special problems, it is sometimes necessary to make a mock up of the equipment being protected at our fire test facilities, and run tests to determine the most effective location, discharge pattern, and piping arrangement.

In essence, we have some basic concepts and pieces of equipment to work with as tools in solving a fire protection problem. How these are combined into an effective system is a matter of application engineering which should be attempted only by those who are thoroughly familiar with and have had experience in this special area of fire protection.

There may be many of you here today who were not aware that a solution to some of your more troublesome fire hazards is available.

We invite you to bring your problems to us and give us a "crack" at solving them.

TECHNIQUES AND CONCEPTS FOR EXTENDING COOK-OFF TIME AND REACTION SEVERITY OF A WARHEAD IN A FIRE

by

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Abstract. The objective of this program is to study the chemical and thermal stability of explosives and verious liner materials. From this study we can identify means by which the cook-off time of e warheed in a fuel fire can be extended and the severity of the cook-off reaction can be reduced. The study given here will cover areas that relate to the explosive, internal liner, case and external coating to the cook-off problem. All these areas of study will be shown to be interrelated and how they can be used to reduce the hazards of cook-off and extend the time to cook-off.

Introduction

The purpose of this program is to alleviate the hazards of fire on the flight deck of an aircraft carrier caused by existing airborne weapons and stores. The basic goal of this study is the development of explosive systems that will eliminate, delay, or minimize the damaging effects of cook-off. There are four general areas under study for extending the cook-off time and reducing the severity of the cook-off reaction. These areas are: explosives, internal liner, case, the external coating and in addition the fire that are shown in Figure 1. The lower the fire output, the longer the time to reaction, but the reaction may be more severe. Since no one area is independent of the other, cooperative efforts are under way in related areas with other groups working on explosives, design, and related decomposition studies. Since all of these areas affect the time and severity of reaction on cook-off such as the type of explosive, liner reactivity, case confinement, heating rate, etc., some basic rules have been realized. First, extinguish the fire if possible. Second, keep the fire from the warhead case by a coating material, third, design case break-up for venting action, and fourth, keep the explosive from the hot metal or case with a liner material. The selection of an explosive for use in a warhead is critical, since some explosives detonate with more ease than others. What can be done in each area is covered below.

Coating Materiel

Studies ere being conducted on coatings that are (Figure 2):

1. Pure insulator (non-reacting (est. 5-20 mil)).

2. Intumescent materiel that intumesce at selected temperature to match the liner decomposition for outgaseing end inhibiting ection on the explosive. This allows a longer time for liner decomposition.

3. Allow rapid cooling on the warhead.

Case Design

The desired features for the case are (Figure 2):

1. A groove inside the case for venting action.

2. A design break-up pattern for venting ection.

3. Use of a steel that loses its tensile strength repidly above 1000°F.

4. Vent plugs. Theee are not recommended unless incorporated with en inhibiting/outgassing type of liner.

Liner Material

In this aree, the following items are considered importent in the development of a suiteble liner (Figure 3):

1. Pura ineulator (non-reecting).

2. Structural stability (keep explosive away from metal or case surface.

3. Outgassing edditive (vent case).

4. Inhibiting additive of the burning rate type (prevent pulse burning and DDT).

5. Endothermic decompoaition (heet sink).

6. Compatib'lity of liner end explosive.

7. Prevention of explosive migration through liner cese interfece.

Rather than studying eech of the above items eeperately, all ere considered during the development of e liner material. The binder materiel and chemical additives ere studied before a liner io developed and the methods used are shown in Figure 4. The tests ere used to determine possible pit-fells with certein binder end chemicals with explosives.

Explosives

In this eree, the following topics ere covered in the study on making explosives that give less violent reactions under confinement and repid heating (Figure 5).

1. Studying inhibiting additives to prevent pulse-type burning and deflegration detonation trensition (DDT).

2. Studying explosive compositions with e low percentage of small particle size eluminum that may not degrade the detonation velocity in shape charges, etc.

3. Development of explosives with high transition pressure values and a low burning rete slope.

4. Studying explosive compositions with higher thermal stability.

5. Developing binders with decomposition reactions that degrade an explosive et elevated temperature.

Under part (1) Glazkova (Reference 1) hes suggested several chemical

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Ref. 1. Glazkova, A.P "The possibility of decreasing the rate of combustion of explosives by the addition of reducing agents," DOKLADY PHYS. CHEM. (USSR), Vol 181, Nos. 1-3 (July 1968), p. 510.

additives for use in explosives that act as burning rate inhibitors. These additives are considered to be reducing agents which, in theory, inhibit the auto-catalytic effect of the decomposition products on the explosives. The testing of the explosives with various additives is conducted in a similar manner as outlined in Figure 4 in regard to all the areas above.

Progress to Date

Several differant types of coating and liner materials have been tested to date and show good promise. These have been tested in a warhead that has heavy confinement and with an explosive that has been a problem. Figure 6 shows the thermal profile of each thermocouple located within the warhead. These cover the internal temperature at the liner-case interface and the explosive-liner interface with respect to time. Also the reaction severity is listed at the end for each test. The best liner to date is a polybutadiene (Butarez) binder with an outgassing chemical, ammonium oxalate. A United Kingdom intumescent paint is used and the explosive (Composition B) has been one that detonates with ease.

These are only a small part of the study now in progress. Many liner materials including new binders, hot melts, etc. and many outgassing chemicals have been studied and are being reported. The application to new weapons is in progress also. (Figure 7).

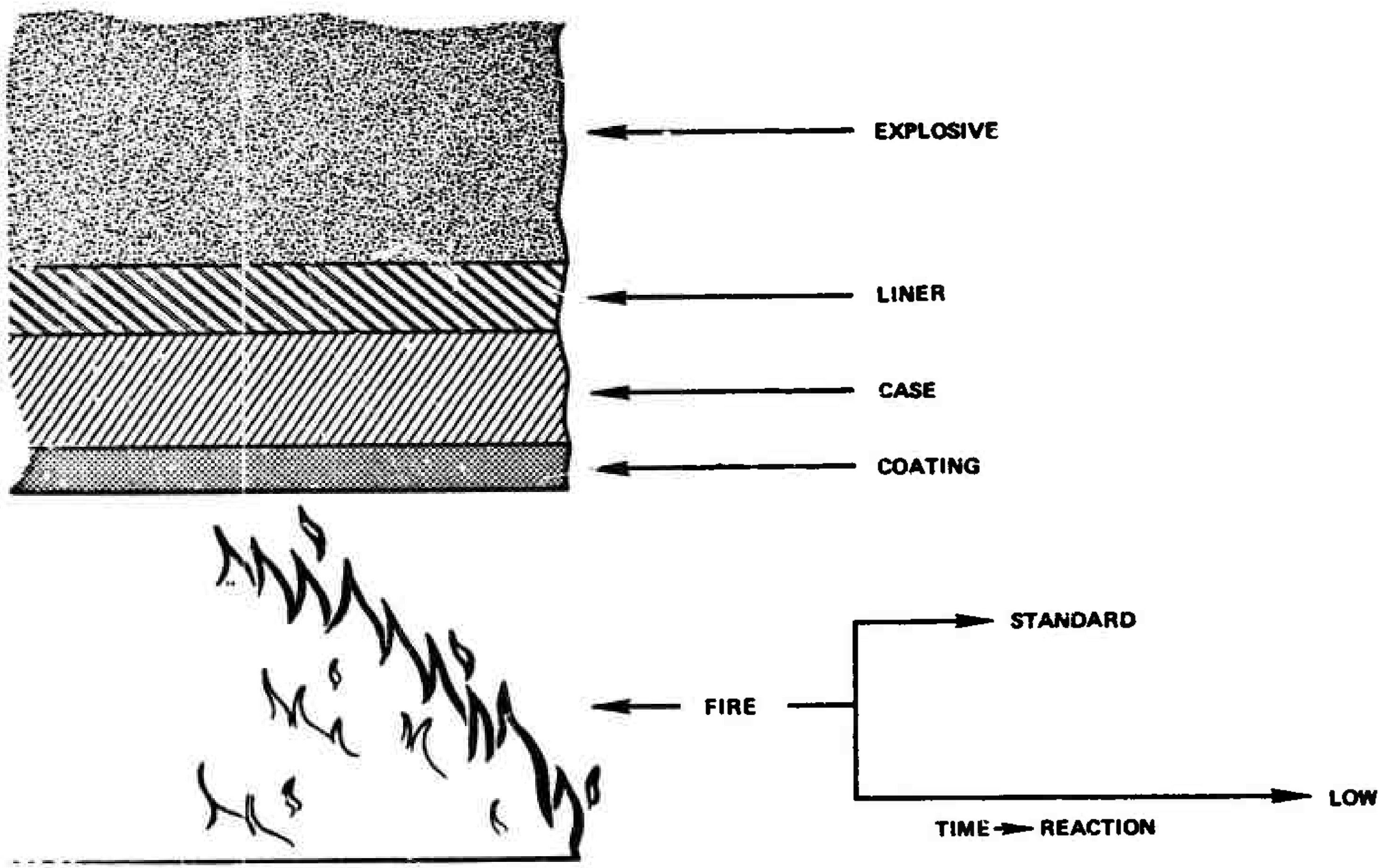

Fig. 1. Areas of Study to Extend Cook-off Time and Reduce Reaction Severity.

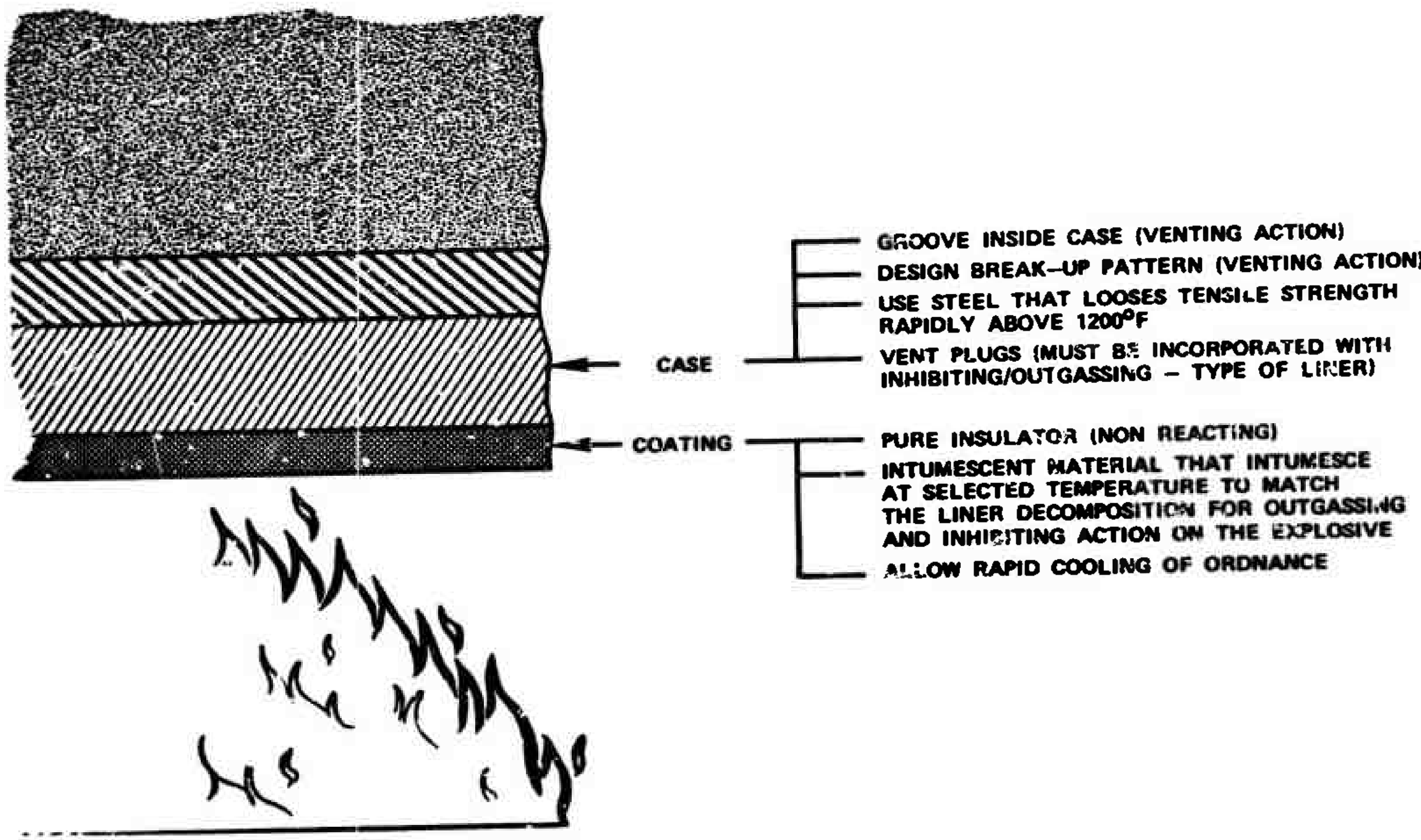

Fig. 2. The Case and Coating Areas of Study.

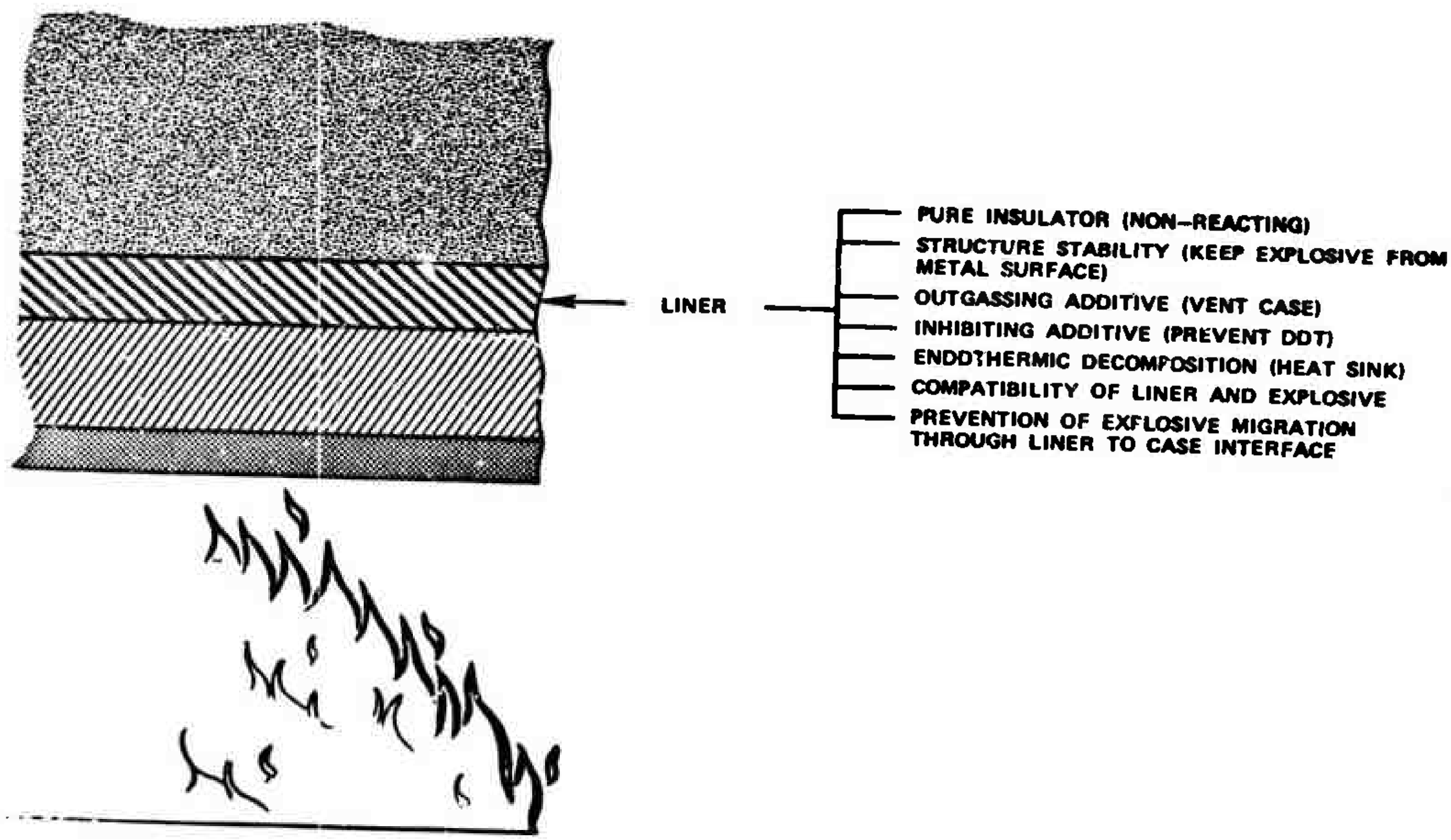

Fig. 3. The Liner Area of Study.

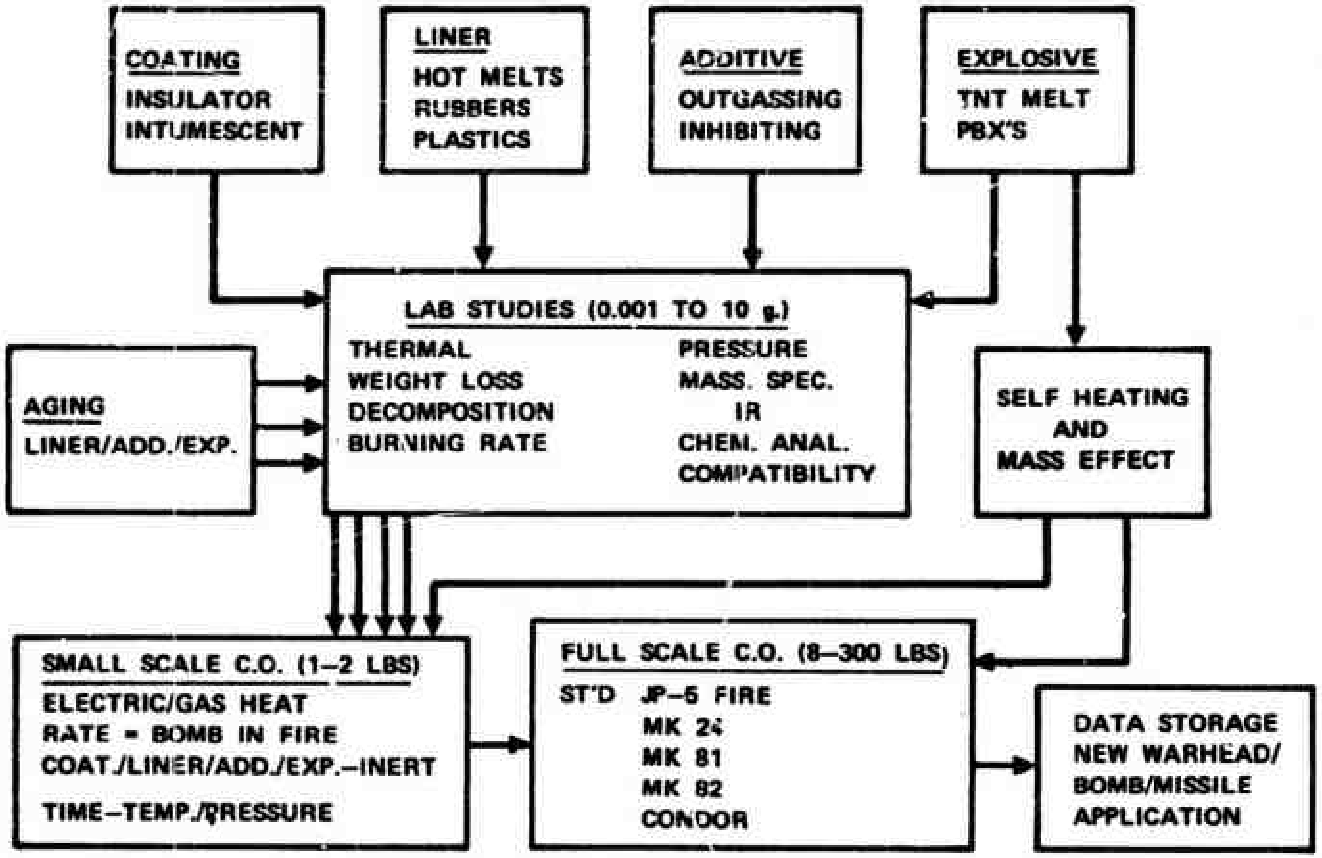

Fig. 4. Study Outline Procedures.

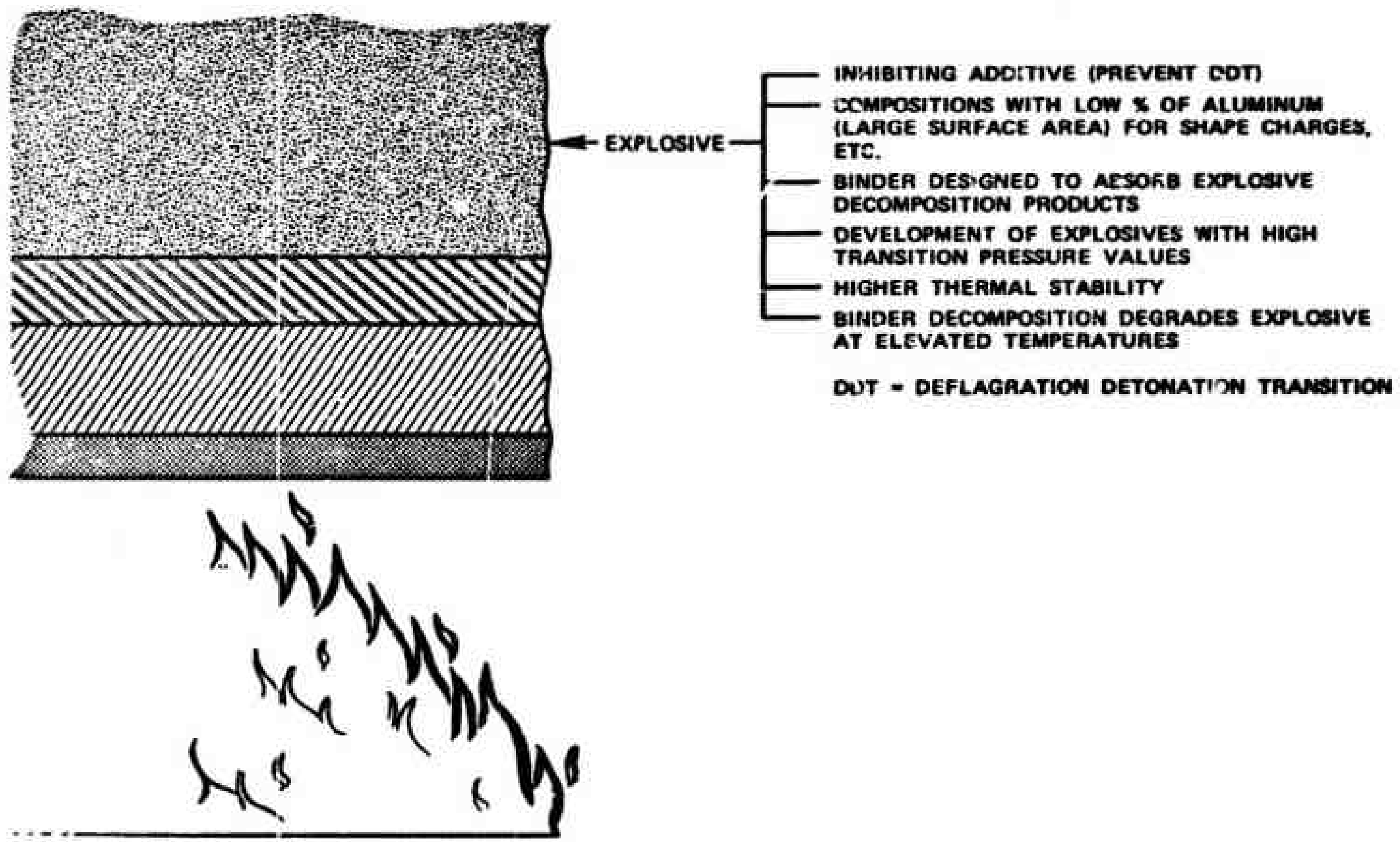

Fig. 5. The Explosive Area of Study.

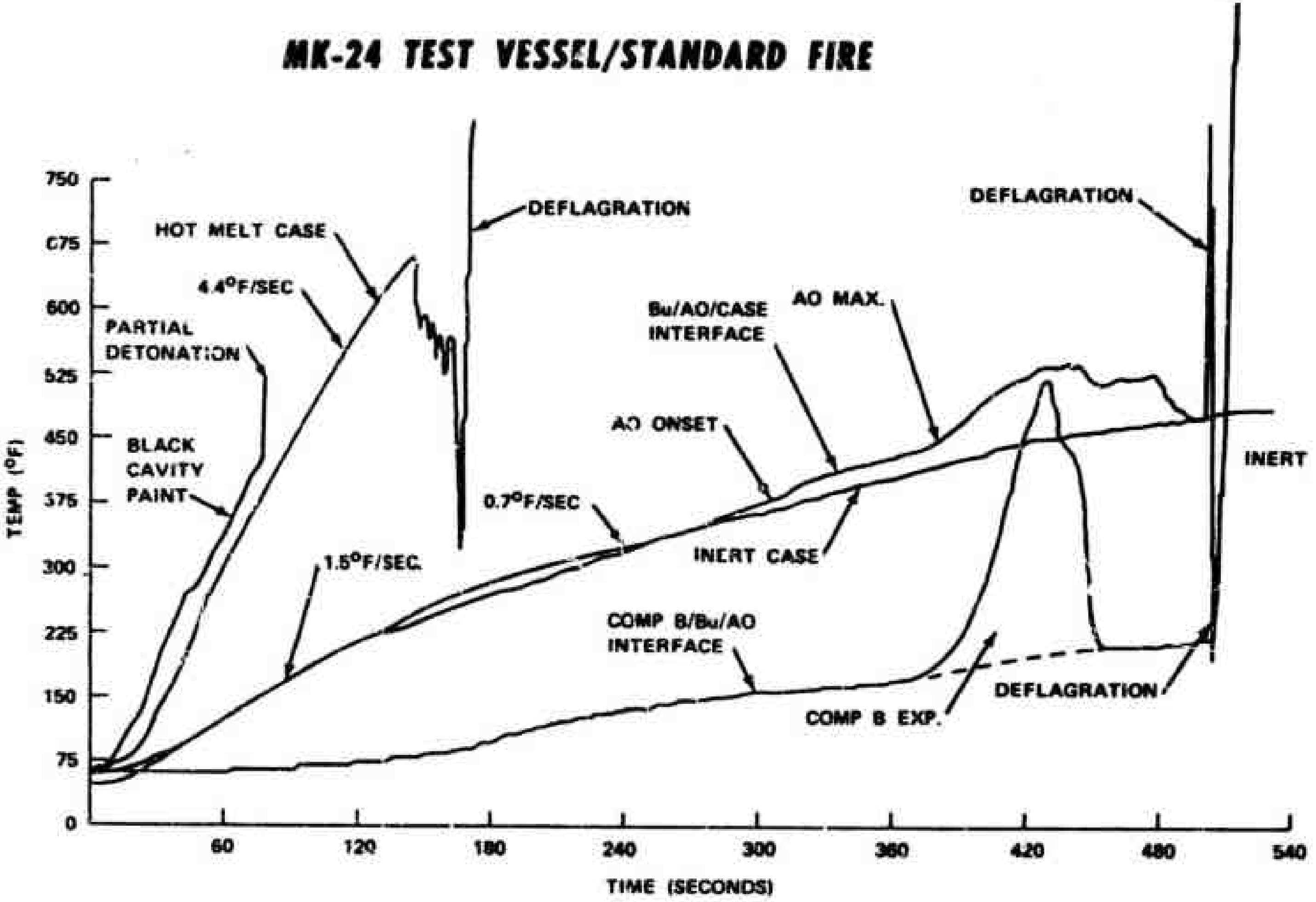

Fig. 6. Mk-24 Warhead Test Vessel in a Standard JP-5 Fuel Fire.

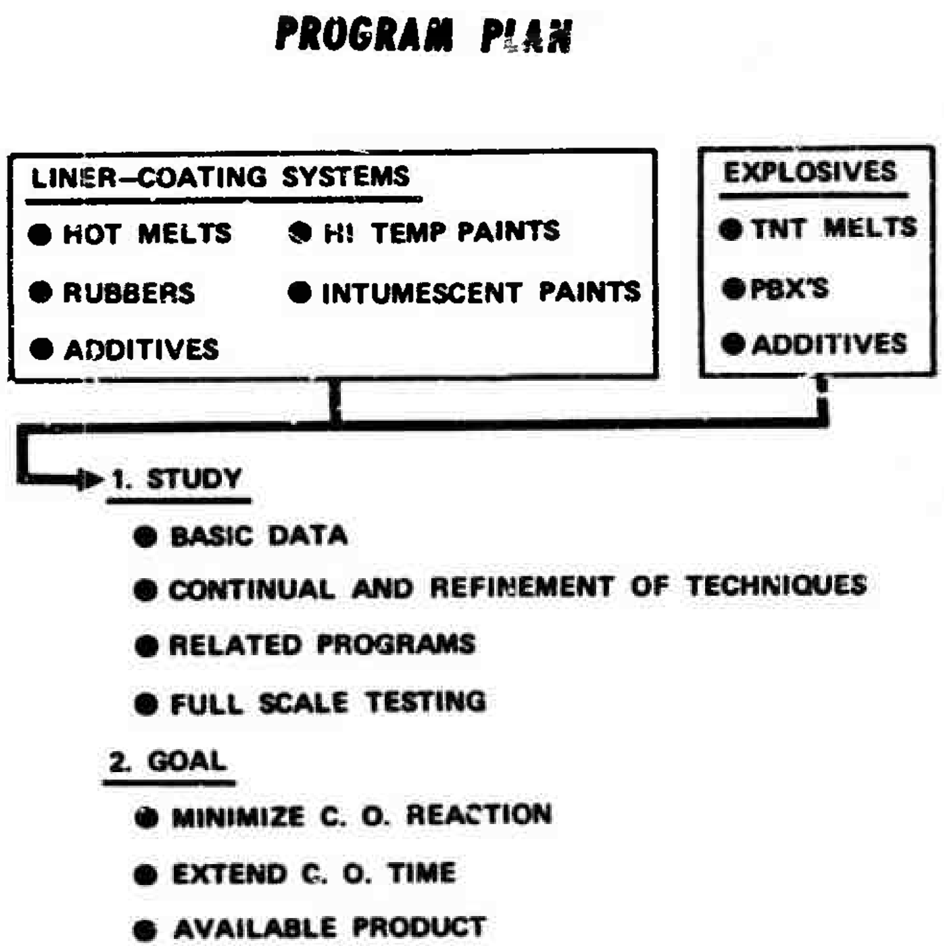

Fig. 7. Program Plans of Study.

CONTROL OF FAST FIRES IN ARSENAL POWDER LOADING AREAS

A. H. Petersen
Honeywell, Inc.
Minneapolis, Minnesota

Automatic Fire Suppression of the types of fires commonly found in arsenals require immediate and reliable fire detection and energization of a suppression system.

Todays fire protection technology has made available faster and much more reliable fire detection.

The fire protection system that I will describe to you will employ ultra violet sensing fire detectors to activate a detonator actuated water deluge valve.

This paper will describe the operation of the ultra violet fire sensing detector and deluge valve separately for ease of explanation.

An obvious question is why was ultra violet fire sensing detection selected?

Reason: Because ultra violet fire detectors would eliminate almost 100% of the false actuations attributed to other types of fast fire detectors and still maintain instantaneous response time.

There are a number of different types of fire detectors on the market today (show slide 1)

The most commonly known and used are the thermal and rate of rise type of fire detector. However, since they require a temperature buildup for actuation they would not be considered a means to energize a fast water deluge system.

Smoke ionization detectors, products of Combustion Detectors and Smoke Reflective Detectors would also respond too slow because of the transmission time for the products of a fire to reach a detector.

To obtain the instantaneous response required for Arsenal fire detection applications, optical or radiation detectors must be used. These detectors do not require a transportation time to respond since electromagnetic radiation travels at the speed of light at approximately 186,000 miles per second.

The three types of optical detectors are:

Visible light detectors

Infra Red Detectors

Ultra Violet Detectors

A slide of the electromagnetic spectrum is probably the best means to describe each of these detectors. (Slide 2)

The electromagnetic spectrum can be divided into seven categories. Starting with the shortest wave length to the longer, these categories are:

Cosmic Rays

Gamma Rays

X-Ray

Ultra Violet

Visible light

Infra Red

Radar, T.V., Radio

However, for purposes of our discussion, we will only concern ourselves with the ultra violet, visible light and infra-red wave lengths. You will note that a photo cell or light detector will respond not only to fire but to most forms of ambient light and therefore is only used in limited applications. Infra red detectors also respond to a wide spectrum and therefore are sensitive to sunlight, intense artificial light and hot refractory. It is easy to see then that a narrow spectral response is necessary to reduce the possibility of false or nuisance signals. The wave length of sensitivity for the Honeywell Ultra Violet detector is 1850-2450 angstroms. This narrow spectrum of sensitivity prevents UV Sensing Systems to

detect radiation from sources other than fire. It is also important to note that radiation from the sun and artificial lighting does not fall into this detectors region of sensitivity and due to this feature the detector can be used in areas of direct sunlight and intense light. The radiation that a UV detector is sensitive to is the UV light emitted from the Chemical reaction of combustion. In a fire, UV light is emitted from high temperature carbon atoms and is emitted during the formation of water, carbon monoxide and carbon dioxide. The flames from almost every fire result in the formation of water, CO and CO_2 and as a result will emit UV. The magnitude of the UV emitted will, of course, vary with the fire size and the temperature of the fire.

Tests conducted for existing arsenal and industrial applications indicate ignited pyrotechnic and illuminating flare materials emit tremendous amounts of UV light. Therefore a UV detector is very sensitive to a very small ignition even at a considerable distance.

To understand how the UV sensor works, one must understand the Geiger-Muller principle. A text book definition of the "Geiger-Muller Detector" states that a "Geiger-Muller Detector" is a radiation detector having a anode and cathode contained

in an ionizable gas. When the cathode is exposed to UV radiation to which it is sensitive an electron is emitted and because of the applied voltage causes the gas to become ionized and a discharge of current to flow. In effect you might look at the tube as being a switch without any moving parts and therefore without any wear out mode. Thereby the detector can offer the same reliable fire protection today, tomorrow or a year from now without change.

(Slide 3) The detector has been designed for use in most hazardous atmospheres. The Detector housing is both explosion proof and weather proof meeting Class I Group D, Class II, Groups E, F, and G. (Slide 4) The detector module is mounted in energy absorbing material and it currently used in applications where shock and vibration are present.

Because of their reliability and speed UV fire detectors are in operation throughout industry, protecting people and equipment in hazardous areas. Some of the applications other than the subject arsenal are (Slide 5) off shore drilling and production platforms. Every production or

storage area aboard these Alaskan rigs is supervised. Because of the potential fire hazard and the severe temperature of the glacier fed waters, the name of the game is reliable fire detection. This, of course, is true in pipeline terminals, gas compression stations, chemical plants or any application where highly combustible materials are used.

The Honeywell UV system was recently chosen by the (Slide 6) Bureau of Mines as the means to detect an incipient methane explosion generated by an underground continuous coal mining machine. The specification requires a 6" diameter methane ignition be detected at twenty five feet and completely suppress it with a dry chemical in less than 70 milleseconds. To visualize this, the methane ignition is detected when it is the size of a softball and suppressed before it reaches the size of a basketball.

UV was also recently installed aboard the Skylab (Slide 7) module for fire protection during its mission when launched next spring.

The subject Army Ammunition Plants application is regarded as a primary water deluge system to protect a powder bagging and sealing production line. This unique system was designed by the Fike Metal Products Company to eliminate the excessive water damage which accompanies total flooding by a main deluge or sprinkler system.

The Fike system consists of total fire detection and extinguishing capabilities complete with its own water supply tanks. It was designed to protect arsenal production operations considered the most likely areas of ignitions. The Systems' principle is that fire in its incipient stage can be extinguished by a water deluge of a small supply during the short period of measurable time between ignition and the buildup of a fast fire.

The system is comprised of five modular or main assemblies.

1. The Control Panel
2. The Deluge Valves
3. The Water Supply tanks
4. The Manifold and Nozzles
5. The Honeywell Ultra Violet Sensors.

The Control Panel is a supervisory panel for the deluge valve firing circuit. Panel indicator lights visually show system status when armed. An emergency fire button is available for manual discharge of the system.

The Fike Deluge valve contains a prescored rupture disc with a pyrotechnic shape charge attached to its face that is operated automatically by the signal from a detection system. A fire signal received from the Ultra Violet sensor is sent to the detonator assembly located on the deluge valve. The detonator sets off the shape charge on the rupture disc, causing an immediate opening. From the time the detonator receives the fire signal until the valve is completely open is less than 5 milleseconds. The versatile design of the deluge valve allows it to be installed in standard ASA flange ratings and used in conjunction with practically any quenching media.

The supply tanks and manifold assembly consist of a 50 gallon water supply tank used to protect the sewing machine on the powder bagging line. Since this was considered the most hazardous area, the manifold assembly is preprimed to

allow instant delivery of water in the shortest period of time. The bag sealing operation has only a one gallon water supply for protection. Although both areas are protected by a minimal amount of water, the systems fast response will extinguish an ignition before total flooding of a main deluge system is required.

As you can see the marriage of a UV fire detection system with a detonated deluge valve provides an ultra fast fire protection system for arsenal and like applications.

The concept is unique because it is the first time an arsenal area has been monitored visually without any problem of false alarms due to lighting or reflected light sources. In addition this system completely eliminates the necessity of building light barriers or shields required previously by other detection systems. Because of these advantages existing detection systems are being retrofitted with Honeywell UV fire detection systems and specified for modernization programs.

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CLOSING REMARKS

Colonel William Cameron III, USAF, Chairman
Department of Defense Explosives Safety Board

Again we have completed the explosives safety seminar - our 14th. In taking leave of you I would like to thank everyone for the interest and attention which indicates your continuing vital concern with explosives safety matters.

At the Explosives Safety Board, since a year ago known as the Department of Defense Explosives Safety Board, we take a great deal of pride in these seminars. They evolve from an initial meeting in 1959 and, attended incidentally by ninety people, on special problems connected with the manufacture of new types of solid propellants.

As you have seen from the technical papers presented during this seminar, the scope has broadened considerably. We have tried both to address the theoretical aspects of explosives safety and to show you their practical applications. I hope that we have succeeded in keeping it interesting for the wide range of specialized skills this audience embodies.

In the past three days, papers have been presented on a wide range of subjects bearing on explosives safety. The emphasis has been on the application of new ideas and developments to practical safety problems. For example, several papers described applications of hazards analysis techniques to manufacturing processes. In a session on production plant modernization, we heard several case studies of facilities improvement in which design for safety is one of the foremost considerations. We have also heard talks on efforts toward improved hazard classification systems which realistically reflect the true risk involved.

Through our own technical program, we at the Explosives Safety Board have developed standards for safer, more economical utilization of storage magazines, and we have moved ahead in our efforts to characterize the fragment and debris hazards from stored ammunition. Although we have made significant progress in this phase, the work is by no means finished.

We have, however, been able to translate the preliminary results into some explosion effects computation aids that can be used for quick estimation of the decreasing hazard at various distances as one goes outward from the source of an explosion. These have been forwarded to the Military Departments for evaluation. We hope they can become useful additions to the available literature on the subject. They will reduce the uncertainty which surrounds much of the granting of waivers as it has occurred in the past.

I want to caution against a conclusion, however, that all is well and that we can rest on our laurels. Much work remains to be done not only to improve overall safety but to keep a tight rein on the costs of achieving it. There are serious uncertainties, as an example, in the prediction of blast overpressures from non-ideal explosions. In the case of very close-in exposures to our standard earth covered igloos, recent work has shown that these overpressures are much less than would be expected from open stacks and this works in our favor. It is also a strong arguing point for the use of earth covered storage in some situations, where the controlling authorities resist building the covered storage because of budgetary constraints.

We have also demonstrated that the extent of fragment hazard cannot be evaluated by simple rules based on easy extrapolation of the effects of single round bursts. In addition, a serious hazard from fragments may override that from blast at larger distances, that is, for greater quantities of explosives than many of us had thought for years. Some revision of regulations and thinking is mandatory.

We will be busy and actively pursuing your interests in the days and months to come. Let us hope that by the next seminar we will have additional progress to report.

I am most appreciative of those who contributed their professional talents, in spite of very busy schedules, to prepare and deliver the many worthwhile presentations we have heard in the past three days. They have contributed a great deal to the overall success of the meeting.

I would like also to thank the members of the Secretariat for their assistance in arranging for a stimulating technical program and the high quality of facilities and service support.

In conclusion, again let me extend to all of you my sincere appreciation for your help and interest in making this our best seminar. Thank you.

ATTENDEES

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BECHER, A. F.	Edgewood Arsenal, Md.

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